Science: Philosophy, History and Education

Michael R. Matthews *Editor*

History, Philosophy and Science Teaching

New Perspectives

Springer

Science: Philosophy, History and Education

Scope of the Series

This book series serves as a venue for the exchange of the complementary perspectives of science educators and HPS scholars. History and philosophy of science (HPS) contributes a lot to science education and there is currently an increased interest for exploring this relationship further. Science educators have started delving into the details of HPS scholarship, often in collaboration with HPS scholars. In addition, and perhaps most importantly, HPS scholars have come to realize that they have a lot to contribute to science education, predominantly in two domains: a) understanding concepts and b) understanding the nature of science. In order to teach about central science concepts such as “force”, “adaptation”, “electron” etc, the contribution of HPS scholars is fundamental in answering questions such as: a) When was the concept created or coined? What was its initial meaning and how different is it today? Accordingly, in order to teach about the nature of science the contribution of HPS scholar is crucial in clarifying the characteristics of scientific knowledge and in presenting exemplar cases from the history of science that provide an authentic image of how science has been done. The series aims to publish authoritative and comprehensive books and to establish that HPS-informed science education should be the norm and not some special case. This series complements the journal Science & Education http://www.springer.com/journal/11191Book Proposals should be sent to the Publishing Editor at bernadette.ohmer@springer.com.

More information about this series at http://www.springer.com/series/13387

Michael R. Matthews
Editor

History, Philosophy and Science Teaching

New Perspectives

Springer

Editor
Michael R. Matthews
School of Education
University of New South Wales
Sydney, NSW, Australia

ISSN 2520-8594 ISSN 2520-8608 (electronic)
Science: Philosophy, History and Education
ISBN 978-3-319-62614-7 ISBN 978-3-319-62616-1 (eBook)
DOI 10.1007/978-3-319-62616-1

Library of Congress Control Number: 2017951229

Printed on acid-free paper

This Springer imprint is published by Springer Nature
The registered company is Springer International Publishing AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Foreword

Although there are many scholars who have contributed significantly to bringing the history and philosophy of science (HPS) and science education closer together, there is no single person who has done more than Michael Matthews. Michael has not only been the editor-in-chief of *Science & Education* for 25 years, since its inception in 1990, but also an active ambassador of HPS-informed science education. He has travelled all over the globe to numerous conferences where he has promoted the aims of the IHPST group and *Science & Education.* He has also been keen in bringing people to the IHPST as authors and reviewers. Last but not least, he has written and edited several books on HPS and science teaching.

Michael's most recent achievement is the enormous, and of enormous importance, *International Handbook of Research in History, Philosophy and Science Teaching*, published by Springer in 2014. This is a three-volume book with contributions by 130 researchers from 30 countries – an amazing achievement. It is the first-ever handbook surveying the past and present of research on history, philosophy and science teaching, and in its 75 chapters, several pedagogical, theoretical, biographical and national research traditions are discussed. Therefore, one might think that with such an enormous work, there would be several years before anyone attempted to develop another book of this kind.

Yet, this is not the case. What you are holding is another book of this kind and once again edited by Michael Matthews. Not surprisingly, this book does not overlap with the *Handbook* but aims to complement it. But in this case, the editor made sure that there is an additional element: novelty in perspectives. Therefore, the present book is not intended to be the fourth volume of the *Handbook* but a stand-alone book that covers a number of topics that are not usually treated in the HPS&ST literature. These topics include feng shui, Enlightenment, indoctrination, science and culture and a lot more. Of course, there are also more 'traditional' topics covered, either methods-oriented such as nature of science and epistemic practices or concept-focused such as energy and evolution, but again the perspectives are different than those usually found in books.

All in all, the present book stands as evidence that there will always be new ways to look at the same topics, insofar as one is willing to do so. Of course, not many people have been in the field for as many years as Michael Matthews, and it is very likely that nobody is as aware of the range of current work as he is. This is why it has been possible for Michael to come up with the present volume after completing the *Handbook*. I trust that researchers will find this book useful, as they have found the *Handbook*, which currently has more than 150,000 chapter downloads. Most importantly, I hope that researchers will be inspired by the present book to come up with new ways that HPS can inform science teaching and learning.

University of Geneva
Switzerland

Kostas Kampourakis
Series Editor

Contents

Part I Science, Culture and Education

1 Feng Shui: Educational Responsibilities and Opportunities 3
Michael R. Matthews

2 The Enlightenment: Truths Behind a Misleading Abstraction 43
Robert Nola

3 The Enlightenment Tradition and Science Education in Turkey 67
Deniz Peker and Özgür Taskin

4 Cultural Studies of Science Education: An Appraisal 99
Christine L. McCarthy

Part II Teaching and Learning Science

5 Epistemic Practices and Science Education 139
Gregory J. Kelly and Peter Licona

6 Strategies for Learning Nature of Science Knowledge: A Perspective from Educational Psychology 167
Erin E. Peters-Burton

7 About the Psychological and Logical Moment in Natural Science Teaching (1890) 195
Ernst Mach

Part III Curriculum Development and Justification

8 Scientific Knowledge as a Culture: A Paradigm for Meaningful Teaching and Learning of Science 203
Igal Galili

9 Integrating Science Education Research and History and Philosophy of Science in Developing an Energy Curriculum 235
Yaron Lehavi and Bat-Sheva Eylon

10 Teaching Evolution: Criticism of Common Justifications and the Proposal of a More Warranted Set 261
Mike U. Smith

Part IV Indoctrination and Science Education

11 Science Education, Indoctrination, and the Hidden Curriculum 283
Lena Hansson

12 Warranted Indoctrination in Science Education 307
Paul A. Wagner

Name Index 317

Subject Index 323

New Perspectives in History, Philosophy and Science Teaching: An Introduction

Introduction

Research relating the history and philosophy of science to theoretical, curricular and pedagogical issues in science teaching (HPS&ST research) has been conducted for over a century. Its institutionalised or disciplinary beginnings can be dated from 1887 when Ernst Mach, the German physicist, philosopher, historian and educator, founded the world's first science education journal – *Zeitschrift für den Physikalischen und Chemischen Unterricht*.[1] In the USA, John Dewey and Lloyd Taylor explicitly addressed HPS&ST issues in the 1920s and 1930s. James Conant, Gerald Holton, Stephen G. Brush, Leo Klopfer, Robert S. Cohen, Joseph Schwab, Otto Blüh and Arnold Arons made significant contributions to the tradition through the 1950s and 1960s. In the UK, HPS&ST issues were addressed by Thomas Henry Huxley in the nineteenth century; from the 1920s in books and articles by Frederick Westaway, Eric Holmyard and James Partington; and in the 1960s and subsequently by John Bradley, Joan Solomon and others. HPS&ST investigations are also found in Spanish, Portuguese, French, German, Italian, Finnish and Asian educational research traditions.[2] All of this work was published in various philosophy, history and education journals and book series.

That there should be such a tradition of HPS&ST scholarship is not surprising: Any intelligent and informed teaching of a subject inevitably leads teachers and curriculum writers towards an appreciation and understanding of the history, epistemology and ontology of the subject they teach, organise and frame for students. The same holds for mathematics, economics, psychology, theology and all disciplines.

A landmark in the history of HPS&ST research was the launching in 1992 of the Springer-published journal, *Science & Education: Contributions from History and Philosophy of Science*. This was, and is, the first scholarly journal devoted entirely to HPS&ST research. It began modestly with four numbers per year and has grown

[1] Pleasingly Mach's journal is archived on the web.

[2] An outline of the tradition of HPS&ST can be found in Matthews (2015a, Chaps.1–3).

both in size and in scholarly recognition. In 1997 it moved to six numbers, in 2003 to eight numbers and in 2007 to ten numbers per volume. In 2011 there were 108,650 article downloads from its Springer site.[3]

Much of the last 30 years of HPS&ST research was detailed and appraised in the 3-volume, 76-chapter, 125-author, 2544-page Springer *International Handbook of Research in History, Philosophy and Science Teaching* (Matthews 2014a). The *Handbook's* subject index contained 2,000 entries and its name index had 3,600 entries. The chapters were grouped into four sections, Pedagogical Studies, Theoretical Studies, Regional Studies and Biographical Studies, with each section being further subdivided. Indicative of the vitality of the HPS&ST research, there have been 100,000 chapter downloads from its Springer site in the two years it has been available.

In the past three decades, there have been hundreds of papers published on nature of science and its implications for teaching, learning, science curriculum and teacher education programmes. This is commonly cited as 'NOS research' and it has had enormous international impact in research, teacher education and curriculum writing.[4] Although often not seen as such, it is another segment of the broader HPS&ST research tradition.[5]

Although extensive, the *Handbook* did not exhaust the spectrum of HPS&ST studies. This anthology of *New Perspectives in History, Philosophy and Science Teaching Research* takes up some fields that were not included in the *Handbook* (the Enlightenment tradition, cultural studies and indoctrination) and develops some that were.

Structure and Contents

This anthology of 12 reviewed articles grouped in four sections deals either with aspects of HPS&ST research not covered in the *Handbook* (the chapters on the Enlightenment tradition and on indoctrination) or with research that has risen in importance over the past few years. The first section of four chapters deals with the pressing issue of understanding the interrelation between science, science education and the cultural tradition of the Enlightenment.

The first chapter, 'Feng Shui: Educational Responsibilities and Opportunities', is a new contribution to the perennial and important topic of 'science education and

[3] Something of the origins, history, content and impact of the journal can be read in Matthews (2015b).

[4] For reviews of NOS research, see Erduran and Dagher (2014), Hodson (2014) and Lederman et al. (2014).

[5] Three papers connecting NOS research to the wider spectrum of HPS&ST studies are Matthews (1997, 2004a,b). Some of the philosophical issues raised, but not adequately addressed, by contemporary NOS research have been canvassed in Matthews (2012, 2015a, Chap.11).

worldviews'.[6] The chapter describes how feng shui belief and practice is an ancient and still significant worldview in Chinese and Southeast Asian cultures and how it has an increasing commercial and personal presence in other cultures. It documents the unexpected, almost total neglect of feng shui in educational and philosophical literature, especially in accounts of pseudoscience and of 'alternative sciences'. A brief account of the history of feng shui is given, with special attention paid to two early encounters between feng shui and Western science and worldviews: first, the Jesuit priest Matteo Ricci (1552–1610) and, second, the Protestant missionary Ernst Johann Eitel (1838–1908). These are chosen in part for their own historical importance but also because the philosophical, cultural and educational dimensions of the two 'encounters' still resonate whenever and wherever issues of modernisation and multicultural science arise. The chapter elaborates efforts at cultural modernisation in twentieth-century China, including the Communist Party's efforts in this regard, and how these sought to excise feng shui from personal and cultural life in China.

Debate over the possibility of demarcating science from pseudoscience is examined, and arguments are given for maintaining the distinction against those wanting to dissolve it and, more strongly, for regarding feng shui as a pseudoscience. The claim is made that it is a responsibility of education, specifically science education, to engage with and promote the refinement of students' worldviews, the more so when those views encompass events, processes and mechanisms in the natural world, the world about which science provides unrivalled knowledge. Science education can provide practice in requiring beliefs to be linked to evidence and practice in the more sophisticated appraisal of competing beliefs. Such training can flow over to beliefs and commitments in politics, history, religion, economics and government policy. Such engagement and flow-over are a contribution of science education to the cultural health of societies. This was the hope of the Enlightenment philosophers who thought widespread science education could counteract the prejudice, superstition, illusion, fantasy and unchecked harmful social and political programmes so rife in their age; it remains the hope of most contemporary science educators.

Robert Nola's second chapter, 'The Enlightenment: Truths Behind a Misleading Abstraction', brings philosophical and historical refinement to a core issue in science education, namely, the connection between modern science education and the eighteenth-century sociocultural-historical movement known as the 'European Enlightenment' (*le Siècle des Lumières* or *Aufklärung*). One unfortunate omission from the *Handbook*, and more generally from contemporary science education discussion, is the 'The Enlightenment Tradition in Science Education'. The eighteenth-century Enlightenment philosophers – John Locke (1632–1704), Baruch Spinoza (1632–1677), Voltaire (1694–1778), Jean D'Alembert (1717–1783), Denis Diderot (1713–1784), Nicolas de Condorcet (1743–1794), Julien de la Mettrie (1709–1751), David Hume (1711–1776) and a little later Benjamin Franklin (1706–1790), Joseph Priestley (1733–1804), Thomas Jefferson (1743–1826) and Immanuel Kant (1724–

[6] On this subject, see Matthews (2009b, 2014b) and contributions to Matthews (2009a).

1804) – were inspired by the dramatic achievements of the new science of the seventeenth century. Of this founding group, Isaiah Berlin well said:

> The intellectual power, honesty, lucidity, courage and disinterested love of the truth of the most gifted thinkers of the eighteenth century remain to this day without parallel. Their age is one of the best and most hopeful episodes in the life of mankind. (Berlin 1956, p.29)

The eighteenth-century Enlightenment was the fruit of the seventeenth-century scientific revolution. It was not a monolithic grouping holding to a 'party line'; they held a diverse set of philosophical, religious and political views, but nevertheless certain core commitments can be identified, and the holding of which warrants an individual's inclusion in the Enlightenment movement (Matthews 2015a, pp.23–26, Shimony 1997).[7]

The Enlightenment put large-scale, society-wide education on the cultural and political map. It was distinguished, among other things, by its commitment to social and cultural improvement, to progress, and this was to be achieved through education broadly understood to include periodicals, newspapers, books, colleges and embryonic schools (Shimony 1997). The hallmark of Enlightenment education was to be the spread of scientific (natural philosophy) knowledge and outlooks. Enlightenment figures believed in 'science for all' some three centuries before it became a popular educational slogan (Brock 1996). This commitment to expansive science education has marked all educators explicitly aligned to the Enlightenment tradition – Ernst Mach, Thomas Huxley, John Dewey and Gerald Holton, to name just some.[8]

The Enlightenment tradition deserves to be a core topic in science education. Its educational, cultural, religious, political, historical and philosophical dimensions are deep, rich and demanding; the topic is, one might say, very illuminating. There can be productive cooperation between school science, history, religion, economics, politics and literature teachers if more were known of the scientific roots of the Enlightenment. The intimate connection of science, politics and the Enlightenment in the foundation of the USA (Cohen 1995, Koch 1965, Stewart 2014) is an obvious illuminating cross-disciplinary case study that can be, with benefit, repeated for just about all countries. Such cross-faculty collaboration can bring some cohesion to the fragmented, unconnected subject divisions that school students' experience.

The Enlightenment tradition has many detractors, both within and outside modernism. Contemporary postmodernism is basically defined in terms of its rejection of the historic Enlightenment project; wherever postmodernism holds sway, all, or most, of the Enlightenment's commitments are abandoned. Assuredly the Enlightenment is out of favour in education; it is seen to be intimately connected to ills, real and imagined, of universalism, imperialism, rationalism and patriarchy. The Enlightenment's connection to embryonic democratic movements, opposition

---

[7] There are numerous scholarly studies of the Enlightenment (see, for instance, Himmelfarb 2004, Israel 2001, Outram 2005, Porter 2000), while three recent 'popular' expositions and defences are Grayling (2007), Pagden (2013) and Postman (1999).

[8] For an outline of this research tradition, see Matthews (2015a Chap.2), and for different national HPS&ST traditions, see individual chapters in Matthews (2014a, Section 3).

to political and religious absolutism, support for universal human rights, secularism (as in the separation of church and state, the separation of sin from crime), freedom of the press, open debate, freedom of association, an open and civil society and promotion of the critical, including self-critical, spirit or habit of mind is less often recognised. What is living and what is dead in the historic European Enlightenment movement need to be disentangled, and a good education would endeavour to do so. HPS-informed science teachers can contribute wonderfully to this project.

Overwhelmingly modern science education appeals to and extols Enlightenment-grounded commitments: the importance of evidence; rejection of simple authority as the arbiter of epistemic matters; a preparedness to change opinions and theories; recognising the interdependence of disciplines; pursuing knowledge for advancement of personal and social welfare; resisting the imposition of political, religious and ideological pressures on curriculum development and classroom teaching; and so on. These commitments are mostly made without awareness of their Enlightenment roots. It is important for educators to connect these contemporary commitments with their historical scientific-philosophical base and to be aware of the trajectories and philosophical-political-religious buffeting that the commitments have experienced over time. If the past is known, it can be learnt from, and teachers can develop a sense of belonging to an open-minded, critical, scholarly tradition and hopefully defend it.[9]

Nola's chapter asks: What does the name 'The Enlightenment' refer to? Sometimes it is used merely to name a period of time in European history. Sometimes it is used to refer to some body of doctrine (though often what doctrine is unclear). On other occasions, it is used to refer to people who advanced such bodies of doctrine. Such a nominalisation obscures the use of the adjective 'enlightened' to name some property of a person. The chapter attempts to say what this property is and shows how it underpins an epidemiology of being enlightened, that is, an account of the distribution of enlightened as opposed to unenlightened people, in a given society at a given time. This gives the kernel of truth that the nominalisation 'The Enlightenment' obscures. It also helps show that some recent criticisms of 'The Enlightenment' fall quite short of their mark.

The chapter argues that, introducing the idea of the epidemiology of Enlightenment, one can begin to see how excessive focus on a nominalisation of what is more properly adjectival can lead one astray. Talk of 'The Enlightenment' can be a convenient shorthand, but it comes at the cost of taking the nominalisation at face value and assuming that there is a definite 'object' to be spoken about. The epidemiology of being enlightened tells us what are the real facts hidden behind the veil of a nominalising abstraction.

Deniz Peker and Özgür Taskin's third chapter, 'The Enlightenment Tradition and Science Education in Turkey', provides a case study of the subject introduced by Nola. The chapter argues that the Enlightenment tradition in modern Turkey cannot be understood without first examining the Enlightenment tradition in the late Ottoman Empire. The original Enlightenment tradition in Europe emerged as a

[9] Neil Postman (1999) provides a clear and informed elaboration of this argument.

reaction to the church and state's dogmatism and oppression in quest for a more rational and sceptical worldview and a freer more open society. The Ottoman Empire had different societal dynamics than Western Europe, so to understand the Enlightenment tradition in Ottoman times, one needs to pay attention to these differences.

The Ottoman Empire occupied a massive land area spread over three continents. Within this big diversity of geography and population, it is hard to imagine a unified view of an Enlightenment phenomenon for Ottoman societies. Nonetheless, the Ottoman Empire was a very bureaucratic, centralised state, somehow distant from the societies it includes. Thus, focusing on the changes and transformations on Ottoman state and Turkey, their structures and policies on education since the conception of European Enlightenment provide good reference points for understanding the Enlightenment movement in the Ottoman Empire and its successor, the Republic of Turkey.

However, a chronological order of events alone is not sufficient to capture the complexity of the Enlightenment tradition in Turkey. One needs to look at the social, cultural, philosophical and political backdrop of these events, with particular attention to the tension between secularism and religious conservatism. The chapter presents the Enlightenment tradition by examining some of the key events in several distinct historical periods from late Ottoman through today's Turkey while providing cultural, social and political contexts for these events.

Clearly more such national studies of 'science education and the Enlightenment tradition' need to be undertaken, and hopefully they will be. There is a clear case for such studies of Enlightenment-engaged science education in the USA, England, Brazil, Argentina, France, Spain, Portugal, China, Japan and Finland – to identify just the most obvious candidates for further research.

India is a noteworthy case where the introduction of Enlightenment-informed science education in a country, and its subsequent contested history, provides material for philosophical, political and educational analysis and hence lessons. The Constitution of the newly independent India had many claims to international attention, but one is unique. Article 51A(h) of the Constitution of India, co-written by Jawaharlal Nehru and Bhimrao Ambedkar, states that a fundamental duty of the state is *To develop the scientific temper, humanism and the spirit of inquiry and reform.* How did this explicitly Enlightenment provision get there, what has it achieved, and what intellectual, educational and political controversy has it occasioned? These are all engaging questions that repay serious research and that illuminate current curriculum and pedagogy debates in India.[10] Comparable research on Pakistan, which was co-created with modern India but whose founding educational power brokers rejected the Enlightenment tradition, would be rewarding.[11]

[10] An outline of the India case, and consequent debate about cultivation of scientific temper ('Habits of Mind', as more generally known, as a goal of science education, can be read in Matthews (2015a, pp.48–50).

[11] In a 2016 HPS&ST conference address in Pusan, the dean of education at a major Pakistan university laid out the depressing litany of problems bedevilling the country's education and laid

Christine McCarthy's fourth chapter, 'Cultural Studies of Science Education: A Philosophical Appraisal', documents how the newly emergent research field of cultural studies of science education (CSSE) came to prominence with the launching in 2006 of the Springer journal of the same name and a little later a Springer book series of the same name. The founding editors of the journal and book series, Kenneth Tobin and Wolff-Michael Roth, were also two of the most prominent drivers of, and prolific writers in, the constructivist research programme in science education and protagonists in the 'constructivist controversies' that were ignited by early philosophical criticisms of the doctrine. The CSSE programme rejects the Enlightenment project; such rejection is an identifier of the CSSE tradition.

The conceptual contradictions and simple confusions of constructivism were detailed by Wallis Suchting (1992) and in Matthews (1992, 1993). The former provided a detailed, philosophically informed, line-by-line critique of von Glasersfeld's hugely popular version of constructivism that was championed by both Tobin and Roth. Suchting concluded that:

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

The critique was ignored, and the constructivist caravan moved on over the educational landscape with unfortunate consequences for student learning of mathematics, literacy and science and harming graduate education and teacher-education programmes where belief in the doctrine verged on being compulsory. Symptomatic of the times is that in the mid-1990s I gave a talk critical of constructivism at the Harvard Graduate School of Education and students told me that it was the first time they had heard any criticism of the doctrine since enrolling in the programme. And that was at Harvard, the supposed jewel in the education crown.

After the early critiques published in *Science & Education* and elsewhere (Solomon 1994, Osborne 1996), the range of philosophical problems occasioned by constructivism were laid out by contributors to Matthews (1998). Later research focussed, to put it gently, on the pedagogical deficiencies of the doctrine. That these are substantial and warranted is confirmed by the fact that the word 'constructivism' has now entirely disappeared from the annual NARST conference programme.[12]

As Ken Tobin has now 'moved on' from constructivism (Tobin 2000) and Wolff-Michael Roth has now 'abandoned the constructivist paradigm as a useful theory … because [it is] plagued with considerable contradictions' (Roth 2006), the emergent field of CSSE research needs to be examined to see if the well-known philosophical problems of constructivism have been carried over into its replacement programme.

---

responsibility for most of them on the founding fathers' rejection of the 'Enlightenment' education policies adopted in India 70 years ago.

[12] The critical studies are outlined in Matthews (2015b, pp.782–789).

An issue now is whether CSSE is a case of old and discredited philosophical wine in new bottles. McCarthy takes up this question.

A great deal of patient, useful work has been done in examination of the interrelations of science, philosophy and culture. Ernst Mach, so often decried by educators as a narrow-minded, scientistic positivist, wrote:

> The historical investigation of the development of a science is most needful, lest the principles treasured up in it become a system of half-understood prescripts, or worse, a system of *prejudices*. Historical investigation not only promotes the understanding of that which now is, but also brings new possibilities before us, by showing that which exists to be in great measure *conventional* and *accidental*. (Mach 1893/1974, p.316)

George Sarton, arguably the founder of the *discipline* of history of science, wrote in his foundational work:

> In this book pains have been taken to evoke the social background of living science … Science never developed in a social vacuum, and in the case of each individual it never developed in a psychologic vacuum. (Sarton 1952, p.xiii)

In 1994, William Cobern, in introducing a new section in the long-established journal *Science Education,* wrote:

> This section serves as a forum for the critical discussion of cultural, sociological, and political influences on all aspects of science education. Its purpose is to bring a cross-cultural and international perspective to science education that will broaden awareness within the community of science educators, wherever they may be, that science education is a global activity. (Cobern 1994, p.217)

The study of ethno-science is a well-established anthropological research tradition from which science educators can learn. There are serious pedagogical and utilitarian issues about how science can best and most effectively and respectively be taught in diverse different cultures each with diverse worldviews. Such 'critical discussion' has been reported in different journals, including *CSSE*. But the basic issue is not pedagogical but philosophical: what is the aim and what should ultimately be taught in the 'global activity' of science education? Is it 'global' in the sense of everywhere having the same goals? Is it universal science or local (ethno) science that is to be taught? In the most recent iteration of CSSE, what needs to be identified is the degree to which the constructivist origins of the field have influenced its methodological, epistemological and even political research commitments.

A central issue is whether the CSSE subject matter, namely, the interdependence of science, culture and education, can be studied in a *scientific* or *social-scientific* way as Mach or Sarton did or whether the 'new' discipline has its own distinctive methodology and truth tests. The latter is suggested by the opening editorial of *CSSE* where it is stated that 'A requisite for all published articles is, however, an explicit and appropriate connection with and immersion in cultural studies' (Roth 2006; Tobin 2000, p.1). And a few pages later, that research will be published provided it 'is consistent with the forms of inquiry that characterize the research' (p.7). This is very close to a 'only insiders need apply' policy and gives rise to important methodological and political questions about scholarly publishing.

Not surprisingly there is carry-over from CSSE's constructivist birthing to its current decade-old form. McCarthy's chapter documents how the CSSE field has developed a suite of interrelated theses about the nature of modern science that cast doubt on the claims of scientific inquiry to provide the best possible and needed knowledge of the natural and social worlds. The prevalence in CSSE of postmodern interpretations of the nature of science, the nature of knowledge and the nature of truth fuels public doubt about modern science, its practices and its findings.[13] There is a pervasive intercultural and intracultural relativism in the CSSE literature; indeed, commitment to such functions as a shibboleth for the tradition. This is intellectually, politically and culturally both unsound and dangerous. Harry Collins, one of the foremost proponents of the Edinburgh/Bath strong programme in sociology of science, has written:

> The attitude that anyone's opinion on any topic is equally valuable could spread, and there are some indications, such as widespread vaccine scares, that suggest it is happening. A world in which there is said to be no difference between those who know what they are talking about and those who don't is not one that anyone who thinks about it wants. Such a society would be like one's worst nightmare, exhibiting many of the characteristics of the most vile epochs of human history. (Collins 2008)

In contrast to most CSSE advocates, McCarthy argues for a set of philosophical positions she regards as essential for the conduct of modern science: methodological naturalism, pragmatic realism, a correspondence conception of truth and a naturalistic conception of knowledge. There is, of course, serious dispute about each of these positions, but McCarthy lays them out in detail and invites engagement with the arguments. She rejects the common CSSE argument that, because science is not *in*fallible (something on which everyone agrees), then anything or any system of beliefs is equally warranted. McCarthy rightly points out that between epistemological infallibilism and relativism falls fallibilism. And in the latter domain, modern science has no equal in terms of understanding natural mechanisms in the world.

The second section on 'Teaching and Learning Science' begins with Gregory Kelly and Peter Licona's fifth chapter, 'Epistemic Practices and Science Education', which continues this bridge-building between epistemology and the psychology of learning. The chapter draws from the empirical studies of scientific practice to derive implications for science teaching and learning. There has been considerable empirical work from multiple disciplinary perspectives (cognitive science, sociology, anthropology, rhetoric) informing perspectives about science and the inner workings of scientific communities. These studies examine the practices, discourses and cultures of scientists and scientific communities. While the empirical study of science has a considerable history, it is an area often less emphasised in education as compared to the roles of philosophy and history of science for informing education. The chapter details how such empirical studies of science offer insights about science, provide implications for science learning and model ways of investigating knowledge in action.

[13] Further elaboration of this claim can be found in Mackenzie, Good and Brown (2014).

A key contribution of this empirical work on the practice of knowledge construction is the shift in the identification of the epistemic subject from the individual knower to that of a relevant social group. The chapter adds to the work in philosophy identifying limitations to epistemologies based in, or assuming, a Cartesian knowing subject. This shift suggests the need to examine the social processes determining what counts as knowledge, to consider a communal understanding of meaning, to evaluate ideas set in historical and public contexts and to recognise the importance of the assessment of knowledge claims by relevant groups. The chapter might be seen as repeating the point made long ago by Hegel and popularised by Paulo Freire that 'The "we think" determines the "I think"'.

Through a review of science studies, the argument of the chapter for the relevance of a study of epistemic practices is developed. From this point of view, a number of implications for developing conceptual understanding, for learning and for research methodology in science education are derived. The chapter shows how the use of empirical studies of scientific knowledge and knowledge construction processes in schools offers contributions to thinking about science education. This perspective complements the important normative work in epistemology to provide a balanced view of history, philosophy and sociology of science in science education.

Erin Peters-Burton's sixth chapter, 'Strategies for Learning Nature of Science Knowledge: A Perspective from Educational Psychology', begins with the common recognition that learning how to think scientifically is an important, if not vital, skill for an informed citizenry. In order to have a democratic community who can make knowledgeable decisions, citizens need to be able to evaluate the reliability of evidence and to be able to use logic and reason to make choices that result in favourable consequences both for themselves and their society.

The chapter examines the parallels between the ways that nature of science (NOS) knowledge has been taught and the learning processes established by self-regulated learning theory. The chapter bridges the two often separate research fields of the epistemology of subject matters and the psychology of learning those subject matters. The chapter recognises that one mechanism from which to develop student scientific thinking is through the exploration of epistemic cognition in science. The chapter shows that an examination of the history of efforts to create NOS-conscious curriculum over the past 50 years can give insight into how we identify and understand the effective teaching of NOS.

Hayo Siemsen provides the seventh chapter, it being the first published English translation of Ernst Mach's influential 1890 essay 'About the Psychological and Logical Moment in Natural Science Teaching'. The article was published in the world's first science education journal that had been established by Ernst Mach in 1887 – *Zeitschrift für den Physikalischen und Chemischen Unterricht*.[14] The article was titled 'Über das Psychologische und Logische Moment im Naturwissenschaftlichen Unterricht' (1890/91, vol.4 pp.1–5). It was the distillation

[14] Pleasingly the journal is archived on the web.

of Mach's numerous works on pedagogy and educational theory.[15] Mach took as a given that science pedagogy involves both logical (epistemological) and psychological considerations. Mach states his position in the conclusion of the essay:

> One should in teaching first and foremost proceed psychologically; only secondarily and as much logically, as this is enabled through the psychological preparation so that it becomes a need. New concepts, theories, hypotheses, solutions of problems should only be introduced, when the need for this is felt in order to be able to master the topic. For each sentence, which appears during teaching, clarity and explicitness, but in general not indefeasibility from the point of view of the goal of teaching, should be required.

Mach's writings initiated a long 'Machian tradition' of education. The tradition is characterised by having a historically informed or 'heuristic' method; valuing experiential and manipulative ('hands-on') learning; promoting thought experimentation; championing a liberal, coherent and limited curriculum so that *understanding* of subject matter can be achieved; stressing the elaboration of the philosophical content of curriculum material; and directly or indirectly teaching the nature of science.[16]

It is a great pity that there is so little opportunity in any country's science teacher education programmes, or even graduate education programmes, to learn from the life, work and writings of Mach. The same is true of the other significant contributors to the HPS&ST tradition – Thomas Henry Huxley, Frederick Westaway, E.J. Holmyard, John Dewey, Joseph Schwab and numerous others.[17] The history and philosophy of science is not a part of these programmes, and neither is the history of science education. With both HPS and history of education missing, Mach does not appear in pre-service or graduate education programmes that are dominated by other supposedly more practical concerns. But in education, as in science, there is nothing so practical as a good theory, and Mach provides one.

Mach's educational (and philosophical) theory can be elaborated, revised and criticised. It is an orientation and guide to education and pedagogy that rewards engagement. Hopefully this first-ever English translation of his brief piece might lead educators and researchers to give more attention to Mach's life and writings. The notoriously monolingual Anglo-American science education community has a debt to Hayo Siemsen's painstaking translation efforts.

The third section on curriculum development and justification begins with Igal Galili's eighth chapter, 'Scientific Knowledge as a Culture: A Paradigm for Meaningful Teaching and Learning of Science', which starts with recognition that considerable research in science education has focussed on how scientific knowledge is best represented in classrooms so as to facilitate its teaching and learning. Such a goal naturally seeks for the most representative and essential features of scientific knowledge as established in history and philosophy of science (HPS). It

---

[15] For discussion of Mach's extensive educational writings, research and involvements, see Matthews (2015a, Chap.2, 2017) and Siemsen (2014).

[16] The characteristics of the tradition, and its contributors, are elaborated in Matthews (2017).

[17] There are chapters on five of these individuals in the biographical section of Matthews (2014a). More such research needs to be written on others in the tradition.

acknowledges that science teachers require the rudiments of multidisciplinary knowledge: subject matter, pedagogy, cognitive science, history and philosophy of science. Commonly, the first three are addressed in pre-service programmes of teacher training. Yet, even a basic knowledge of history and philosophy of science is often totally lacking in such programmes.

An appropriate way to make up this deficiency is to consider *scientific knowledge* as a cultural system. Doing so opens up opportunities to explore how scientific knowledge mediates human understanding of natural phenomena and how that knowledge is developed through carefully managed processes of investigation and validation. Such a pedagogical approach sees science as an instance of cultural content knowledge (CCK).

A CCK-based curriculum looks to the discourse in the scientific pursuit for knowledge, revealing its characteristic structural features – ontological and epistemological – which otherwise languish in obscurity in the strictly disciplinary teaching of science. CCK reveals the big picture and broader context of scientific knowledge as well as frames and specifies the necessary involvement of HPS in science curriculum construction. Evidence is provided that such a curriculum appeals to a broad population of learners beyond the traditional disciplinary-oriented students and that it keeps with the Enlightenment tradition of dissemination of scientific literacy.

Yaron Lehavi and Bat-Sheva Eylon's ninth chapter, 'Integrating Science Education Research, Science and History and Philosophy of Science in Developing an Energy Curriculum', contributes to applied or pedagogical aspects of the HPS&ST tradition. One of the universally agreed goals of science education is to foster students' understanding of science: the community-generated web of concepts and ideas that aims to explain natural phenomena according to accepted tools and methodology. In addition, students are expected to develop their competency in applying scientific ideas and justifying their application. Hence, a curriculum in science education involves addressing the interpretation of evidence and the reasons for preferring one view over another. Since these considerations are also the focus of the history of science and its philosophy, their utilisation can assist the development of a genuine scientific curriculum.

Curriculum serves both students and teachers so science education research provides another context for curriculum theorising and design. Hence, a curriculum that aims at supplying students with the requisite tools to learn from the evolution of scientific ideas and their foundations, and by those means, foster students' scientific understanding, rests on four pillars: science itself, its history and philosophy and results from science education research. The chapter discusses how each of these four pillars can assist in designing a curriculum for teaching energy at middle school (7th and 9th grade levels) in Israel. Given international concern about the energy crisis and commitments to clean energy, it is valuable to see how HPS plays out in a practical, national curricular context.[18]

---

[18] On contemporary approaches to energy teaching and curricula, see Chen et al. (2014) and the US Department of Energy (2012).

Mike Smith's tenth chapter, 'Teaching Evolution: Criticism of Common Justifications and the Proposal of a More Warranted One', shows that, with cell theory and the DNA theory of inheritance, evolution stands as one of the three pillars of modern biology. Evolution helps us understand phenomena in fields as diverse as genetics, anatomy, ecology and physiology. Understanding evolution is important not just from a scientific perspective but from a practical one as well. Evolutionary theory can help us solve real-world problems that have a biological basis. The chapter shows that while a wide variety of reasons for the inclusion of evolution in the science curriculum have been proposed, too often these justifications make sense to teachers and policy makers but do not appear to be convincing to students; despite all justifications, many students hold out against learning evolutionary theory, and many of those that do learn resist belief in it.

The chapter discusses the types of justifications that have been used to support science literacy in general and evolution understanding in particular. It demonstrates how limited student-centred justifications for evolution literacy are and asks how they can be made stronger. A small set of justifications are proposed that are more relevant, interesting and convincing to students. The chapter concludes by drawing out educational implications of the argument.

The fourth section on indoctrination introduces the important but largely neglected task of the informing science education debates by the discipline of philosophy of education. It begins with Lena Hansson's eleventh chapter, 'Science Education, Indoctrination, and the Hidden Curriculum'. On connections between the two research fields, see Schulz (2014). In Hansson's chapter, the topic of indoctrination is discussed; with the chapter taking as its starting point analyses of the concept of indoctrination in philosophy of education, it provides an overview of the use of the concept in science education. The chapter then focuses on indoctrination through the hidden curriculum, claiming that messages about the image of science communicated in the classroom, which are not in line with the formal curriculum, are part of this hidden curriculum.

It is suggested that widespread views about science (e.g. associating science with positivistic, scientistic, atheistic and modernistic views) could be viewed as the indoctrination of students. It is claimed that since these views are not necessary for science, the image of science becomes distorted for students. Thus, such indoctrination could have unfortunate consequences for the possibility of students embracing science or identifying with it. The issues raised in the chapter return to those in the opening chapter about whether the practice of science is committed to any particular worldview, or more usefully, what characteristics of the world are required to explain the conduct and success of science.

Paul Wagner's twelfth chapter, 'Warranted Indoctrination in Science Education', continues the discussion of indoctrination by asking the following question: Is there a place for indoctrination in science education? The issue surfaces with some regularity, but usually without the necessary historical and philosophical refinement, in education debate. The question arises whenever science education removes itself from student experience and depends overly on authority, the scientific tradition or the testimony of experts.

The problem might appear intractable as a hallmark of modern science is its remove from immediate, unmediated experience and its dependence upon the experimental and confirmed findings of others as reported in journals and books. Everywhere students learn about things they rarely can see or experience – atomic structure, chemical bonding, paleo-climates, arrangement of the solar system, galactic events and so on. Nearly all school science content needs to be learnt second-hand and taken on testimony, hence the need to see how, and indeed if, routine science learning and instruction can be distinguished from indoctrination. The chapter shows that, through to the early part of the twentieth century, the concept of indoctrination was straightforward and generally free of controversy. Ideological agitations likely fermented by several factors such as a misunderstanding of the progressive education movement, reaction to the growth of fascism and communism in Europe especially and student revolts of the 1960s and 1970s brought with them a host of disturbing connotations surrounding the idea of indoctrination.

The chapter notes that the noun *indoctrination* does not name a process or a set of processes. Indoctrination does not denote any malevolent intent on the part of an indoctrinator. Indoctrination does not denote the value or epistemic soundness of any content resulting from one or more processes employed by an indoctrinator; it is claimed that the noun *indoctrination* is best understood as a 'benchmark' term and nothing more. It is a valuable benchmark term and provides generic licence for pedagogical practices that lead to firmly held beliefs without the benefit of personal epistemic grounding.

The chapter's claim is that indoctrination functions as a benchmark when entry levels of disciplinary material have sufficiently 'stuck' in order that learners might pass over the threshold of a new discipline and into independent engagement with those who are more expert in the discipline. The benchmark establishing that the threshold has been successfully secured is manifest when learners are able and inclined to carefully express doubt about knowledge claims within the discipline.

Conclusion

As a guiding curricular principle, Matthew Arnold's claim of nearly 150 years ago (Arnold 1868/1966) that education systems have a responsibility to identify and transmit the best of their culture's heritage is hard to dispute: surely no one would want to advocate its opposite. Modern science is one of the most important parts of the patrimony of humanity; it has long ceased to be a European or Western cultural artefact. The history and philosophy of science allows science teachers and science education researchers to better understand the achievements, the strengths and the weaknesses of science and so their own social and professional responsibilities as part of an important tradition. Consequently, interest and competence in HPS need to be cultivated in teacher education and graduate education courses. Minimally, as Israel Scheffler so succinctly maintained, to teach a discipline, you need to know something of its history and epistemology, and the more of the latter you know, the more valuable for students can be your teaching of the discipline (Scheffler 1973).

Hopefully each of the contributions in this anthology can do something towards broadening the professional vision of science teachers and thus assist in having their students not only arrive at 'mandated' destinations – scientific competence, literacy and appreciation - but arrive with broader horizons. Such positive learning outcomes enable science education to contribute to the cultural health of all societies and cultures.

School of Education
University of New South Wales
Kensington, NSW, Australia

Michael R. Matthews

References

Arnold, M. (1868/1966). In J. Dover Wilson (Ed.), *Culture and anarchy: Landmarks in the history of education*. Cambridge: Cambridge University Press.

Berlin, I. (Ed.). (1956). *The Age of enlightenment: The eighteenth century philosophers*. New York: Mentor Books.

Brock, W. H. (1996). *Science for All: Studies in the history of Victorian science and education*. Aldershot: Variorum Press.

Chen, R. F., Eisenkraft, A., Fortus, D., Krajcik, J., Neumann, K., Nordine, J., & Scheff, A. (2014). *Teaching and learning of energy in K-12 education*. Dordrecht: Springer.

Cobern, W. W. (1994). International science education section: Editorial policy statement. *Science Education, 78*(3), 217–220.

Cohen, I. B. (1995). *Science and the founding fathers: Science in the political thought of Jefferson, Franklin, Adams, and Madison*. New York: W. W. Norton & Company.

Collins, H.M. (2008). An Interview. *American Scientist*. http://www.americanscientist.org/search/home_result.aspx?q=harry%20collins

Department of Energy (DoE) USA. (2012). *Energy literacy: Essential principles an fundamental concepts for energy education*. Washington, DC: US Department of Energy.

Erduran, S., & Dagher, Z. R. (2014). *Reconceptualizing the nature of science for science education*. Dordrecht: Springer.

Grayling, A. C. (2007). *Towards the light: The story of the struggles for liberty & rights that made the modern west*. London: Bloomsbury.

Himmelfarb, G. (2004). *The roads to modernity. The British, French, and American enlightenments*. New York: Alfred A. Knopf.

Hodson, D. (2014). Nature of science in the science curriculum: Origin, development and shifting emphases. In M. R. Matthews (Ed.), *International handbook of research in history, philosophy and science teaching* (pp. 911–970). Dordrecht: Springer.

Israel, J. I. (2001). *Radical enlightenment: Philosophy and the making of modernity 1650–1750*. Oxford: Oxford University Press.

Koch, A. (Ed.). (1965). *The American enlightenment: The shaping of the American experiment and a free society*. New York: George Braziller.

Lederman, N. G., Bartos, S. A., & Lederman, J. (2014). The development, use, and interpretation of nature of science assessments. In M. R. Matthews (Ed.), *International handbook of research in history, philosophy and science teaching* (pp. 971–997). Dordrecht: Springer.

Mach, E. (1893/1974). *The science of mechanics*. (6th edn). La Salle: Open Court Publishing Company.

Mackenzie, J., Good, R., & Brown, J. R. (2014). Postmodernism and science education: An appraisal. In M. R. Matthews (Ed.), *International handbook of research in history, philosophy and science teaching* (pp. 1057–1086). Dordrecht: Springer.

Matthews, M. R. (1992). Old wine in new bottles: A problem with constructivist epistemology. In H. Alexander (Ed.), *Philosophy of education 1992*, Proceedings of the forty-eighth annual meeting of the Philosophy of Education Society. Philosophy of Education Society, Urbana, IL, pp. 303–311.

Matthews, M. R. (1993). Constructivism and science education: Some epistemological problems. *Journal of Science Education and Technology, 2*(1), 359–370.

Matthews, M. R. (1997). James T. Robinson's account of philosophy of science and science teaching: Some lessons for today from the 1960s. *Science Education, 81*(3), 295–315.

Matthews, M. R. (Ed.). (1998). *Constructivism in science education: A philosophical examination*. Dordrecht: Kluwer Academic Publishers.

Matthews, M. R. (2004a). Thomas Kuhn and science education: What lessons can be learnt? *Science Education, 88*(1), 90–118.

Matthews, M. R. (2004b). Reappraising positivism and education: The arguments of Philipp Frank and Herbert Feigl. *Science & Education, 13*(1-2), 7–39.

Matthews, M. R. (Ed.). (2009a). *Science, worldviews and education*. Dordrecht: Springer.

Matthews, M. R. (2009b). Teaching the philosophical and worldview components of science. In M. R. Matthews (Ed.), *Science, worldviews and education* (pp. 49–80). Dordrecht: Springer.

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* (pp. 3–26). Dordrecht: Springer.

Matthews, M. R. (Ed.). (2014a). *International handbook of research in history, philosophy and science teaching* (3 vols.). Dordrecht: Springer.

Matthews, M. R. (2014b). Science, worldviews and education. In M. R. Matthews (Ed.), *International handbook of research in history, philosophy and science teaching* (pp. 1585–1636). Dordrecht: Springer.

Matthews, M. R. (2015a). *Science teaching: The contribution of history and philosophy of science: 20th Anniversary revised and enlarged edition*. New York: Routledge.

Matthews, M. R. (2015b). Reflections on 25-Years of Journal Editorship. *Science & Education, 24*(5–6), 749–805.

Matthews, M. R. (2017). Mach's educational theory and practice. In F. Stadler (Ed.), *Vienna circle institute yearbook*. Berlin: Springer.

Osborne, J. (1996). Beyond constructivism. *Science Education, 80*(1), 53–82.

Outram, D. (2005). *The Enlightenment* (2nd ed.). New York: Cambridge University Press.

Pagden, A. (2013). *The Enlightenment and why it still matters*. Oxford: Oxford University Press.

Porter, R. (2000). *The Enlightenment: Britain and the creation of the modern world*. London: Penguin Books.

Postman, N. (1999). *Building a bridge to the 18th century: How the past can improve our future*. New York: Alfred A. Knopf.

Roth, W.-M. (2006). *Learning science: A singular plural perspective*. Rotterdam: Sense Publishers.

Sarton, G. (1952). *A history of science, volume one: Ancient science through the golden age of greece*. New York: W.W. Norton.

Scheffler, I. (1973). *Philosophy and the curriculum. In his reason and teaching* (pp. 31–41). Indianapolis: Bobbs-Merrill.

Schulz, R. M. (2014). Philosophy of education and science education: A vital but underdeveloped relationship. In M. R. Matthews (Ed.), *International handbook of research in history, philosophy and science teaching* (pp. 1259–1315). Dordrecht: Springer.

Shimony, A. (1997). Presidential address: Some historical and philosophical reflections on science and enlightenment. In L. Darden (Ed.) *Proceedings of the 1996 PSA Meeting*, S1–14.

Siemsen, H. (2014). Ernst Mach: A genetic introduction to his educational theory and pedagogy. In M. R. Matthews (Ed.), *International handbook of research in history, philosophy and science teaching* (pp. 2329–2357). Dordrecht: Springer.

Solomon, J. (1994). The rise and fall of constructivism. *Studies in Science Education, 23*, 1–19.

Stewart, M. (2014). *Nature's god: The heretical origins of the American republic*. New York: W.W. Norton & Co.

Suchting, W. A. (1992). Constructivism deconstructed. *Science & Education, 1*(3), 223–254.

Tobin, K. (2000). Constructivism in science education: Moving on. In D. C. Phillips (Ed.), *Constructivism in education* (pp. 227–253). Chicago: National Society for the Study of Education.

Part I
Science, Culture and Education

Chapter 1
Feng Shui: Educational Responsibilities and Opportunities

Michael R. Matthews

1.1 Introduction

Feng shui is a system of beliefs and practices originating some three to four thousand years ago that is concerned with identifying, charting, and utilizing the supposed all-encompassing flow of chi or *qi*, the putative universal life force, so that people's lives and their habitat can be brought into harmony with it, made more natural, and so improved. It is a worldview and is a significant feature of Chinese and south-east Asian cultures.[1] But it has long migrated from Asia and has an increasing international commercial and personal presence. As a writer in the American Institute of Architects newsletter commented: 'Feng Shui is no longer just an ancient Chinese secret. While slow to take root outside of its original heartland, it is now global and transcends culture and politics' (Knoop 2001). Feng shui is a growth industry, yet it is a neglected topic in science education. It is also ignored in most philosophical discussions of pseudoscience and the demarcation dispute; discussions where it might be expected to be mentioned and used as a case study.

This neglect is an enigma as feng shui is a worldview that makes claims about the constitution of the world and the ways in which humans can most harmoniously live in the world. Unlike many comparable worldviews, feng shui explicitly claims to be scientific. The whole theory and practice of feng shui revolves around the identification and utilisation of universal energy, or chi, that circulates in a defined manner through nature and through specific meridians in people's bodies where purportedly there are 600+ nodes that can be manipulated by acupuncture.[2] This supposed

[1] Feng shui's origins, history, philosophy and applications have been exhaustively written upon. See, among others: Bruun (2008), Bruun and Kalland (1995), Henderson (2010), Huang (1968), and Smith (1991, chap. 4), Yosida (1973).

[2] In the official Chinese Pinyin system of Romanization, the Chinese character is rendered as *Qi*. In

M.R. Matthews (✉)
School of Education, University of New South Wales, Sydney, NSW, Australia
e-mail: m.matthews@unsw.edu.au

M.R. Matthews (ed.), *History, Philosophy and Science Teaching*, Science: Philosophy, History and Education, DOI 10.1007/978-3-319-62616-1_1

energy has remarkable properties that are mapped, harnessed and utilized by masters and this knowledge and technique can be appropriately taught and learnt.

Feng shui occupies just one sector on the wide spectrum of chi-based Eastern beliefs, therapies, and practices. Over some two to three thousand years, under different philosophical and cultural influences, many versions of fundamental chi-based practice have evolved and cemented their social and cultural place. Along with feng shui, others in the spectrum are: Qi Gong, Falun Gong, Tai Chi, and Jin Shin Jyutsu. They all combine chi (*qi*) and work, practice or cultivation (*gong).* Countless books elaborate on the metaphysics and 'science' of the fundamental categories. Ole Bruun writes:

> The concept of *qi*, which may be translated into 'breath' or 'breath of nature', is fundamental to Chinese natural philosophy. It is strongly indicative of an organic predisposition in Chinese thinking in general, as opposed to the mechanistic orientation that became dominant in European natural philosophy after the Middle Ages. (Bruun 2008, p. 108)

The Wikipedia entry for *Qigong* gives a reasonable overview:

> Qigong is traditionally viewed as a practice to cultivate and balance *qi* (chi), translated as 'life-energy' … qigong allows access to higher realms of awareness, awakens one's 'true nature', and helps develop human potential. Qigong is now practiced throughout China and worldwide.

As with most serious issues in science education, the issues addressed in this chapter involve considerations in both philosophy of science and philosophy of education. They include:

- How feng shui constitutes a world view.
- Why feng shui is a pseudoscience.
- How examination of feng shui can contribute to knowledge of basic matters in philosophy of science, and more generally to better understanding of the nature of science.
- How the historical and philosophical examination of feng shui in classrooms can contribute to the cultural health of society.

1.2 The Cultural Contribution of Science Education

Ideally education promotes the well-being of society. That is why so much effort and expenditure is put into education at all levels from pre-school through primary and secondary, to post-school, including university education. Social well-being encompasses personal flourishing, good and equitable economic functioning and

---

the older Wade-Giles system of Romanization the character is rendered as *Chi* which is the Taiwanese usage favoured by most Western scholars. Less frequently the character is written as *Ch'i*. The Korean and Japanese preference for Chi is *Ki*, the word which appears in many of their Chi-based martial arts and therapies.

cultural health. All school subjects make their own contribution to this overall social well-being. Apart from obvious areas of personal knowledge, clear thinking and psychological health, science education, and the culture-wide science literacy it promotes, can make contributions to the cultural health of societies by clarifying and appraising worldviews (Matthews 2009a, b).

In particular, a modicum of science literacy can be useful in identifying worldviews that are inconsistent with science, and especially identifying those purporting to be scientific (Fishman 2009). If clarity can be had about these distinctions, then students are better able to be more conscious, informed, appreciative, but also critical of their own and their culture's worldviews and superstitions. Jon Miller, who for decades has researched science literacy and public understanding of science, well stated this point:

> In addition to understanding basic scientific constructs, it is important for citizens to recognize pseudoscientific constructs that seek to be recognized as scientific. Astrology is a good example. Since 1988, national samples of US adults were asked whether they though that astrology was "very scientific, sort of scientific, or not at all scientific." Throughout this period, approximately 60 percent of US adults recognized astrology as being not at all scientific. (Miller 2004, p. 278)

Which leaves 40% of the population believing astrology is 'very' scientific or 'sort of' scientific. Surveys in the UK have reported 63% of people believing in the paranormal and 67% in astrology (Preece and Baxter 2000). In one survey, 31% of PGCE would-be science teachers believed in ghosts, and 25% believed in the efficacy of crystals to keep people healthy (Preece and Baxter 2000).

Exercising Miller's broader or deeper scientific literacy means students should develop a scientific 'habit of mind'; its development is a mark of effective science education. In the words of the American Association of the Advancement of Science:

> Taken together, these [scientific] values, attitudes, and skills can be thought of as habits of mind because they all relate directly to a person's outlook on knowledge and learning and ways of thinking and acting. (AAAS 1989, p. 133)

1.3 Academic Neglect of Feng Shui

Given the multiple-millions of feng shui believers in Asia and increasingly beyond Asia, and feng shui's immense social, commercial, and personal impact, it is noteworthy that there has been so little appraisal, critical or otherwise, of feng shui in philosophical or educational literature. A whole raft of popular and highly regarded books devoted to pseudoscientific belief systems simply fail to mention feng shui.[3] Nor is it mentioned in the long review article 'Science, Pseudo-science, and Science Falsely So-called' (Thurs and Numbers 2013), or the edited 23-chapter *Philosophy of Pseudoscience* (Pigliucci and Boudry 2013. And, revealingly, feng shui does not

[3] Feng shui is not mentioned in any of the following best-selling books on pseudoscience: Gardner (1981), Grim (1990), Park (2000, 2008), Shermer (1997) or Sagan (1996).

appear in the 35-chapter, 472-page *Chinese Studies in the History and Philosophy of Science and Technology* (Dainian and Cohen 1996). If feng shui were to be treated seriously and critically by historians and philosophers of science, this last Chinese-based anthology would be a natural home for such examination, but there is no such examination.

Despite widespread, and seemingly growing, commitment to feng shui, and despite it so clearly making claims about putative physical processes in the world, that is, sharing the same ‘ground’ as modern science - many years of science education journals can be searched without finding any mention of feng shui. Nor does it appear in the Subject Index of school science textbooks even ones promoted in the Asian market.

This neglect is noteworthy as Asian countries famously top the world in school science achievement: Singapore, South Korea, Hong Kong, Japan, Shanghai and other Chinese centres define the gold standard in the field. These countries are also the gold medallists in feng shui belief. The concurrence of high science achievement along with widespread feng shui belief does raise the question: To what extent does science education promote a scientific habit of mind? Which invites a further question: Can belief in feng shui theory and practice be compatible with a scientific habit of mind? Is something missing from ‘gold standard’ science education if it seemingly has no impact on the cultural breadth and depth of feng shui belief and practice? Is development and exercise of a scientific habit of mind part of the meaning of ‘gold standard’ science education? Can a science education be gold standard if it does not promote a scientific habit of mind? For the Enlightenment tradition, formation of a scientific habit of mind is the core responsibility of science education.

This disjunct between educational results and commitment to non- and anti-scientific beliefs is not confined to Asia and feng shui. It has oft been remarked that in the USA the same pairing of gullibility and education is found, with Sedona (AZ) being perhaps the poster case. One of the hundreds of counter-culture business operations functioning in the town, 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)

Appraisal of feng shui in classrooms gives the opportunity to explicate a number of important issues in science education and in philosophy of science:

- What is the nature of science?
- Can we separate science from proto-science, pseudoscience and just bad science?
- Is pseudoscience a legitimate and useful category?
- What was and is involved in transition from proto-science to science?
- How do we evaluate competing accounts of phenomena?
- What personal and social factors support the near-universal embrace of non-scientific explanations of natural phenomena?
- How can the Asian cultural tradition be respected yet feng shui belief be critically appraised in schools?

1.4 Chi and Feng Shui

Feng shui had its origin three-to-four thousand years ago in China as part of a family of cosmological worldviews in which an all-pervasive life force, or energy, known as chi (or *qi*) bound together nature and man.[4] Before its articulation as a metaphysical cosmology, it was merely the collective, passed-down commonsense of Chinese and other cultures that needed to attend to environmental realities in order to sow, harvest, herd, build houses and villages, and live safely with whatever comfort could be garnered. Feng shui translates literally as ‘wind water’. It is not surprising that this became the name for the all-encompassing cosmological system, as wind and water were the primeval forces that formed landscapes and governed much of life. This was the conceptual milieu from which Taoism emerged and provided the metaphysical and proto-scientific component of systematic feng shui.

Chi is fundamental to the worldview, metaphysics and ‘science’ that ground ancient and contemporary fend shui practices. The name *feng shui* was introduced to Chinese vocabulary and culture by Guo Pu (276–324 AD) in his early fourth century AD *Book of Burial* (Guo 2004). Guo lived during the Jin dynasty (265–420 AD). He was a scholar, diviner, omen interpreter and, as with all Confucian scholars, a commentator on ancient texts. In Guo’s account, feng shui described the properties and behavior of chi which was the basic all-pervasive constituent, or energy, of the world. For Guo, as with all commentators, Chi is borne by wind and diverted or absorbed by water. The *qi* lines were orientated north-south, a property utilized in the early Chinese geomantic compasses, which then became the technological foundation for the lodestone-based magnetic compasses that were later used in the West for navigation, and in Asia for both purposes.[5]

Guo in his *Book of Burial* writes:

> The Classic says that if *qi* rides the wind it is scattered; if it is bounded by water it is held. Ancient men gathered it, causing it not to be scattered and curtailed its area of circulation. Hence this is referred to as *fengshui*. The method of *fengshui* is, first of all, to obtain water and secondly to store from the wind. (Paton 2007, p. 427)

Guo also elaborates on the mechanism of chi saying:

> *Qi* circulates through the earth according to the geodetic force of the earth. It gathers where the geodetic force stops. The *qi* follows the trunk of a hill and branches along its ridges. (Paton 2007, p. 427)

A proper, historically-informed understanding of chi is clearly a major challenge, yet Stephen Field, a translator of Guo’s classic says that ‘*Qi* is the *sine qua non* for any discussion of feng shui’ (Guo 2001). So, this challenge cannot be avoided.

[4] Many works discuss the notion of chi and its place in Chinese philosophy and proto-science. See Chan (1963, 1967), Fung (1947), Yoshida (1973) and Zhang (2002).

[5] On the original Chinese geomantic interpretation and use of the compass see Aczel (2001, chap. 7) and Skinner (2008).

An authoritative modern text on Chinese Philosophy written by Zhang Danian, from Beijing University Philosophy Department, devotes a chapter to Chi. The book provides an informative listing of scores of representative and influential Chinese chi beliefs from ancient times to the present. Zhang summarizes the tradition of chi beliefs as follows:

1. *Qi* is the original material out of which all things are formed by coagulation.
2. *Qi* has breadth and depth and can be spoken of.
3. *Qi* is contrasted with the mind. It exists independent of the mind.
4. *Qi* can move. Indeed, it is normally in a state of flux and transformation. (Zhang 2002, p. 63)

And he adds:

> Hence, what Chinese philosophy says about *qi* is basically the same as what Western philosophy says about matter. The Chinese theory, however, is distinctive on two counts:
>
> 1. *Qi* is not impenetrable; rather, it penetrates all things;
> 2. *Qi* is intrinsically in a state of motion and is normally in flux. (Zhang 2002, p. 63)

Edmund Ryden, the translator of Zhang's book revealingly says:

> Perhaps the best translation of the Chinese word *qi* is provided by Einstein's equation, $e=mc^{2}$. According to this equation, matter and energy are convertible. In places the material element may be to the fore, in others, what we term energy. *Qi* embraces both. … Qi is both what really exists and what has the ability to become… *Qi* is the life principle but it is also the stuff of inanimate objects. … As a philosophical category … [this] meaning is then expanded to encompass all phenomena. (Zhang 2002, p. 45)

Ryden well captures the explicit identification of chi-theorising with basic theory of modern science. Chi beliefs are not meant to be removed from, outside of, or alien to science. Chi believers, or at least theoreticians, avowedly embrace and accommodate the most sophisticated foundational statement of modern science. But unlike orthodox science, there is no history of the conceptual, much less experimental, amplification and refinement of the basic idea.

For instance, Zhang's description of 'coagulation' of elements might parallel a kitchen-chefs's use of the term or maybe an artist's when mixing paint, but it has no connection or comparison with the long history in chemistry of investigating what elements combine with what others to form compounds, the conditions under which the combinations can occur, and the detailed theory of valency which governs such combinations.

Identifying with science, and seeking the public esteem and legitimation that it brings, is a two-edged sword for feng shui: the more explicitly its advocates tout its scientificity, the more pressing is the need for scientific-philosophical appraisal of the worldview and associated geomantic practices. The enigma is that this has not happened in either education or philosophy communities.

The contrast with the long history of Atomism, or even the more recent history of Relativity Theory, is dramatic. In the latter fields, there is detailed, precise testing and elaboration of theory in the light of exact experimental testing, all done in a public, published tradition. Once feng shui claims to be on the same field as science, then this contrast is invited and the deficiency of the former is obvious. An educational and philosophical challenge is to make and appraise the contrast, drawing out implications for the nature of healthy science.

1.5 Feng Shui Practice

Feng shui was never just an idle worldview; from the beginning, it was connected to practice, to decision making about where to live, the configuration of domestic and government buildings, lifestyles, and how to identify auspicious times and foretell futures. Feng shui was linked to geomancy; it was an Eastern version of astrology that was so routine across the entire ancient and medieval worlds, and that still lingers in the modern world, both East and West. The practice side of Feng shui began as a way of building tombs to harness chi currents for the better after-life of ancestors and later became a method of orienting palaces, homes, commercial premises so that they too might achieve harmony with their natural environment (Chen and Wu 2009; Han 2001).

Three thousand years later, for millions of people, feng shui dictates major commercial and domestic construction decisions as well as the proper internal arrangement of offices, homes, kitchens, gardens, furniture and decorations (Mak and So 2015). Millions more rely on feng shui astrological guides to make business decisions and for the timing for significant personal and family events (Lim 2003; Lip 2008), and to guide their decisions in romantic and personal life (Hsu 2003; Leung 2010). Feng shui, for example, has an impact in the Asian hospitality industry where decisions about the location, layout, furnishings, decorations and marketing of hotels, resorts and restaurants are all dependent on advice about good feng shui; and where an institution's bad feng shui is known, poor patronage and economic loss follows.

The universal distribution and flow of chi not only dictates the best-placement of structures to harmonize them with local energy flows, but chi also internalizes and determines the health and well-being of people. Chi is at the heart of all Traditional Chinese Medicine; it purportedly flows along numerous meridians in the body and any interruption to this orderly flow results in pain, illness and disease. Ken Tobin, who before 'moving on' (Tobin 2000), was a world-leader of the constructivist movement in science education has embraced chi-related medical practice, saying:

> The underlying theory relates to Qi, universal energy, and its flows through the body. In the case of humans there are 26 pairs of safety energy locks (SELs) through which Qi flows, providing the life source to the body … When a body is disharmonized, energy can be blocked at or close to the SELs, thereby disrupting one or more of the flows needed to distribute the life force to different parts of the body. (Tobin 2015)

Tobin's claims are typical of feng shui proponents who connect the practice to supposed fundamental cosmic and terrestrial 'energies' that are unknown, undetected and unmeasured by orthodox science. For instance, the International Feng Shui Society (UK) states that:

> Chi, or *qi*, is the oriental word for the vital intangible natural energy that emanates from everything in our universe, a combination of both real and abstract forces: energy from the earth's magnetic field, sunlight, cosmic influences, colour vibrations, the nature of our thoughts and emotions, the form of objects, the quality of the air around us. Depending on whether it flows harmoniously or not, chi influences how a place feels and how we feel in it.[6]

1.6 Commercial Feng Shui

Feng shui belief and practice is wide-spread in China, in Chinese-influenced Asia, and over the past 50 years, increasingly in the West. A study of feng shui in Korea commenced with the statement: 'The importance of geomancy in understanding the East Asian cultural landscape and cultural ecology is difficult to overemphasize' (Yoon 2006, p.xiii). Hong Kong is the pulsating centre of the feng shui industry. One scholar writes that: 'Nowhere in the world is feng shui so intensely integrated into every aspect of social, religious and commercial life as in Hong Kong' (Bruun 2008, p. 136). One website announces that:

> Today Hong Kong is the unofficial heart of feng shui practice. In a city where more than 10,000 masters (called geomancers) now ply their craft, you can feel the power of feng shui everywhere.[7]

Nearly all Hong Kong businesses, big and small, and government departments, consult feng shui experts to determine auspicious dates for deals and programme launches; to create interiors and environments that will bring good fortune for a business; to guide against creating bad feng shui for others that might result in costly legal battles and compensation claims (Emmons 1992). Feng shui advice is expensive. The standard 'tycoon' rate is £2–3 per square inch, repeat: per square inch, not square feet or yard or acre, of building (Moore 2011).

For impact, reach and cost of feng shui, Hong Kong is closely challenged by Taiwan. In 2004 the *Taipei Times* (17 October 2004) estimated that there were 30,000 feng shui practitioners in Taiwan. And they are kept busy. After a serious train derailment in Taipei, the Transport Minister sought the advice of a feng shui master who divined that the main station had bad feng shui, including a faulty bagua symbol on its premises, and so the ministry realigned at considerable expense the station's south entrance (Bruun 2008, p. 135). The opposition transport spokesman counter-claimed that the accident had nothing to do with feng shui but rather with inadequate technical systems and human error due to poor management practices.

---

[6] http://www.fengshuisociety.org.uk/

[7] http://www.hotelclub.com/blog/the-power-of-feng-shui-in-hong-kong/#full-info

This routine dispute invites, indeed demands, the recourse to scientific appraisal of the claims: on what other basis could courts make a determination?

It is increasingly common for architectural design and building construction in San Francisco, Los Angeles, Vancouver, Toronto, London, Sydney, Auckland and most major cities around the world to proceed in accordance with feng shui principles; and even in accordance with neo- or quasi-feng shui principles. Serious Western architectural and construction books (Alexander 1987; Gallagher 1993; Rossbach 1983) and scholarly articles (Marafa 2003; Chen and Wu 2009; Hwangbo 1999, 2002; Mak and Ng 2005) are devoted to feng shui informed location, design, placement and construction (Perry-Hobson 1994; Rossbach 1987). Indicative of this building-industry embrace of feng shui is the title of a recent book: *Scientific Feng Shui for the Built Environment*: *Theories and Applications* (Mak and So 2015). Feng shui is a curriculum subject in various Chinese and US university architecture programmes.

In Southern California, having positive feng shui lines, namely soft or curvy ones, is a featured consideration in the marketing of certain cars and there is even a radio station that gives regular updates on the state of regional and local chi energy lines. It is reported that in Los Angeles feng shui consultants, some earning as much as $750 an hour, were recruited from Hong Kong and Taiwan to redesign entire buildings and, where necessary, install structures that could ward off negative energy surreptitiously infiltrating a room or edifice (Queenan 2002).

The worldwide web has dramatically expanded feng shui influence and business: even in the most isolated places on earth a feng shui consultation is only one click and one credit-card charge away. There are thousands and thousands of feng shui sites on the web that list countless thousands of happy corporate and individual clients. One UK site alone mentions among its satisfied customers: Coca Cola, Orange, British Airways, Hiscox Insurance, Hilton Hotels, Marriott Hotels, and BRE (Building Research Establishment), University of Westminster School of Architecture, the National Health Service, and many more. There are feng shui sites for consultants, businesses, retail outlets, teachers, societies, associations, colleges, practitioners, conferences, seminars, publications, diplomas and much else.

All the foregoing examples of contemporary feng shui practice might be seen as the investigation of *external* or *environmental* feng shui, and the making of appropriate personal and construction decisions in the light of local feng shui. But once you commit to the existence of an all-pervasive life force, energy, or chi that binds together nature and man and governs their harmonization, then the next step is to admit its existence and powers *within* bodies; and to then move to control, redirect and manipulate its flow to enhance good effects (wellness) and minimize bad effects (illness). If chi is everywhere and travels everywhere, why should it stop at a person's skin? This is precisely the basis for numerous Asian acupuncture treatments and therapies. Chi is also the 'physical' foundation for the family of Prāṇa-based, Hindu yoga exercises that seek to marshal and utilize, seemingly, the same all-pervasive life-force.

It was recognized some three-to-four thousand years ago in China when feng shui was first formulated that chi was both outside and inside people. This is noted by Fritjof Capra in his best-selling *The Tao of Physics*:

> Traditional Chinese medicine, too, is based on the balance of *yin* and *yang* in the human body, and any illness is seen as a disruption of this balance. The body is divided into *yin* and *yang* parts. Globally speaking, the inside of the body is *yang*, the body surface is *yin*; the back is *yang*, the front is *yin*; inside the body there are *yin* and *yang* organs. The balance between all these parts is maintained by a continuous flow of *ch'I*, or vital energy, along a system of 'meridians' which contain the acupuncture points. … (Capra 1984, p. 98)

1.7 The Origin and Elaboration of Feng Shui

The ancient cosmological fount of feng shui was codified during the Bronze Age (10th – 4th centuries BCE) in the Confucian classic *Book of Changes* or *Yi jing* (Rutt 1996). One historian said of this work that it is:

> the mother of Chinese divination, having fostered both its diversity and persistence; … feng shui is anchored in its perception of reality … it stands out as the single most important book in Chinese civilization … comparable to the sacred scriptures of the other great civilizations (Bruun 2008, pp. 100–101).

Since the beginning, feng shui has been intimately associated with geomancy, one of numerous systematic forms of divination that have a long history in Asia (March 1968; Smith 1991), but also elsewhere. Many people would like to know what the future holds for them. For thousands of years this has been the lure of astrology in all countries. The name 'geomancy' has its roots in the Ancient Greek *geōmanteía* which translates literally to 'foresight by earth', or 'earth divining'. The practice of divining good and bad fortune by the spread of blown sand had older origins in the Arab world (Skinner 1980, p. 14). This tradition created the geomantic compass, or luopan compass, consisting of a circular, flat, inscribed wooden or brass plate, usually with 40 concentric rings and 24 direction lines, and a centered lodestone needle (Skinner 2008). Most science museums have compass exhibits from ancient times, and modern ones can be bought across the counter or online in most 'esoteric' stores. Lillian Too explains:

> In feng shui, the attributes of the elements influence each of the eight sectors of the compass. The four cardinal and four secondary directions each have a corresponding element. So the easiest method of creating good feng shui is simply to energize the element of each compass sector. Understanding element attributes is thus essential. (Too 1998, p. 42)

1.8 Two Historical Encounters Between Feng Shui and the Western Scientific Worldview

It is informative to examine two moments in the history of contact between feng shui and Western science and philosophy. These historical episodes are illustrative of the general arguments advanced in this chapter and can also serve as suitable 'hooks' for classroom discussion. In particular, there are lessons to be learnt from the celebrated engagements of two Christian missionaries with feng shui. First, the Jesuit priest Matteo Ricci in the late- sixteenth century; second, the Lutheran pastor Ernst Eitel in the mid-nineteenth century. Both episodes have historical, philosophical, political, cultural, theological and scientific dimensions. The episodes can, to whatever degree is appropriate in the classroom and curriculum circumstance, be elaborated with science classes. They also provide ideal cases for cross-disciplinary cooperation among teachers.

1.8.1 Matteo Ricci

Matteo Ricci (1552–1610) was one of the first Europeans to give an informed and detailed appraisal of feng shui belief and practice in China, and certainly one of the first whose account gained wide readership.[8] He was among the earliest, and foremost, of the Jesuit missionaries who were sent to Ming-dynasty China in the late sixteenth century following the thwarted efforts of Francis Xavier.[9] As well as philosophical and religious training at Jesuit universities in Rome, Ricci had serious mathematical, scientific and technical competence. At the *Collegio Romano* he studied mathematics and astronomy with the famed German Jesuit, Christopher Clavius, who was known as 'the Euclid of the sixteenth century'. Clavius was director of the Gregorian calendar reforms; and although an opponent of helio-centrism, he was a confidant of Galileo and they exchanged mathematical and astronomical papers. The Jesuits he trained were the vehicle for bringing Galileo's arguments, telescope and more generally the best European astronomy to China.

With 14 fellow Jesuit missionaries, Ricci left Lisbon in 1578 sailing to Goa where he spent 3 years completing theology studies; then sailed on to and arrived in Portuguese Macao in 1582. There he immersed himself in the study of Chinese language, literature, customs and history. His quick mastery of so much completely novel material was abetted by his astonishing, and much commented-upon memory. After one reading, he could repeat random lists of hundreds of characters. He had

[8] For studies of Ricci's life and influence see: Cronin (1955), d'Elia (1960), Hsia (2012), Spence (1984), Rule (1986), Tang (2015b) and Wright (2010).

[9] On the early history of the sixteenth-century Jesuit missions, and their precursors, see Rule (1986).

written an essay on memory during his studies in Rome.[10] Ricci's life in China is a justly celebrated 'first contact' between Western philosophy and theology and Eastern religion, metaphysics and culture, and consequently something from which a better understanding of both traditions can be obtained. In 1583 Ricci began his 27-year sojourn in China. It was a country for whose culture and achievements he had the greatest admiration, incorporating many customs within the practice of the embryonic Chinese Catholicism that he and fellow Jesuits were establishing. In 1615 Ricci's travel journal, *On the Christian Mission among the Chinese*, was published posthumously in Rome in Latin with the oversight of his fellow Jesuit Nicolas Trigault.

Ricci's mathematical, astronomical and chronological knowledge was taken up in a purely utilitarian way by the Chinese court and mandarins; it was seen to improve astronomy, astrology and calendar calculations upon which so much of the functioning of the Emperor's state apparatus depended. Ricci's 'natural philosophy', or his Western science, had minimal impact on Chinese science and no impact on Chinese culture.[11] Those who accepted the science, held an early version of the later nineteenth-century Chinese traditionalist moto: 'Chinese learning for the fundamental principles, Western learning for practical application'.

Chapter Nine of Book One of the *Journal* is titled 'Concerning Certain Rites, Superstitious and Otherwise'. Ricci's opening admonition is: 'I would request of the reader that he recognize in the two following chapters a reason for sympathizing with this people and for praying God for their salvation' (Ricci 1953, p. 82). He then proceeds by noting:

> No superstition is so common to the entire kingdom as that which pertains to the observance of certain days and hours as being good or bad, lucky or unlucky, in which to act or to refrain from acting, because the result of everything they do is supposed to depend upon a measurement of time. This imposture has assumed such a semblance of truth among them that two calendars are edited every year, written by the astrologers of the crown and published by public authority. These almanacs are sold in such great quantities that every house has a supply of them …and in them one finds directions as to what should be done and what should be left undone for each particular day, and what precise time each and everything should be done. In this manner the entire year is carefully mapped out in exact detail. (Ricci 1953, pp. 82–83)

Ricci elaborated on divination:

> These people worry a great deal about judging their whole lives and fortunes as dependent upon the exact moment of birth, and so everyone makes an inquiry as to that precise moment and takes an accurate note of it. Masters of this kind of fortune-telling are numerous everywhere …(Ricci 1953, p. 83)

And he observes, not unexpectedly, that:

> Fraud is so common and new methods of deceiving are of such daily occurrence that a simple and credulous people are easily led into error. These soothsayers frequently have

[10] On Ricci's memory feats, see Spence (1984).

[11] There was strong opposition to Jesuit science by Confucian traditionalists. This is elaborated in Wong (1963).

> confederates in a gathering who declare to a crowd that everything that was told to them by the performer came to pass just as he had predicted it. Sometimes, too, when strangers are brought in as confederates and relate marvels of the past, the followers of the local imposter respond with loud applause. The result is that many deceived by this trickery, have their own fortunes told and accept what is predicted for them as the certain truth. (Ricci 1953, pp. 83–84)

Geomancy was thoroughly embedded in Ming dynasty (1368–1644) life, the practice being codified in the 1445 *Daoist Canon* that contained entire sections of geomantic charts for divination purpose. Few civil and military decisions were made without geomantic input; by law, no official building construction could commence without geomantic certification (Skinner 2015). Ricci regarded all of this as a *superstitio absurdissima* observing that:

> What could be more absurd than their imagining that the safety of a family, honors, and their entire existence must depend upon such trifles as a door being opened from one side or another, as rain falling into a courtyard from the right or from the left, a window opened here or there, or one roof being higher than another? (Ricci 1953)

1.8.2 Ernst Johann Eitel

Two hundred and fifty years after Matteo Ricci's landmark account of the early engagement of European natural philosophy and religion with Chinese culture, another missionary, Sinologist and linguist covered the same ground. This was Ernst Johann Eitel (1838–1908), a German Lutheran missionary with a doctoral degree from the University of Tübingen, who lived for many years in Hong Kong, who travelled within China, who oversaw educational enterprises in Hong Kong, who published a history of the colony (Eitel 1983), and who published translation dictionaries and studies of Buddhism (Eitel 1873). Importantly he published a substantial appraisal of the history, metaphysics and functioning of feng shui - *Feng Shui: The Rudiments of Natural Science in China* (Eitel 1987). The book provides opportunity for elaboration of wider issues concerning feng shui, science and society, science and experiment, science in China, and science and worldviews. These are all issues that can easily and naturally be discussed in science classes.

1.8.2.1 Feng Shui as a 'Black Art'

Eitel notes how the European construction in the Treaty Ports that followed the mid-nineteenth century Opium Wars, was constantly embroiled in feng shui disputes about the work's expected positive and negative impacts on the flow and distribution of chi in the port area. He observes how much of the foreigners' building work in Hong Kong inadvertently turned out to be in 'good' feng shui sites (access to water, protection from high wind, away from malaria swamps, and so on) which led many Chinese to impute advanced feng shui knowledge to foreigners.

This is the relatively harmless, near trivial face of feng shui – do what common sense and accumulated experience suggests and then call it ‘feng shui guided’. For instance, all feng shui site-selection manuals point out that invisible chi is blown away by wind and is accumulated and borne by water (Han 2001). Thus, attention to wind and water (the original meaning of feng shui) as indicators of chi is of paramount importance and consequently ideal feng shui sites should not be windswept and should be located near water.

No one needs cosmology and metaphysics to come to this conclusion. Water is beneficial in all ways: for drinking, plant growth, temperature control, transport, and so on. Good ecological and common-sense reasons suggest proximity to water and avoidance of wind tunnels make for good living places. People claiming this conclusion as warrant for feng shui belief are committing the elementary logical mistake of affirming the consequent:

Feng shui → site A will be healthy and beneficial.
Site A is healthy and beneficial.
∴ Feng shui is proved/warranted/confirmed/established/vindicated.

But, of course, any number of other ‘theories’, including scientifically informed ones, can equally suggest site A. Further, if site A turns out not to be healthy and beneficial, then other theories, especially scientifically-based ones, can suggest local reasons why this might be so and consequently can give guidance on rectification or remediation of the local problem. It is not clear how feng shui theory can, on its own, do this. The theory is just an idle distraction.

Feng shui cannot make considered adjustments in the way that scientifically informed predictors of site A can make adjustments in the event that A turns out not to be favourable: ecological theories (acid rain), climatological (rising sea levels), geological (seismic activity) or economic (property values) - can explain the divergence from expectation. Feng shui consultants claim that with water, sun and chi plants grow. A proper science education should lead students to inquire whether plants will grow with just two of these - water and sun. A classroom challenge will be to see how chi can be removed from the experimental set-up, as it is supposedly all pervasive. But if it cannot be removed, then equally gravitation or space could be identified as necessary for plant growth. It becomes apparent that chi is just an idle passenger; it is along for the experimental ride.

Quite predictably, two researchers report how feng shui-informed and feng shui-uninformed architects come to the same conclusion about the suitability of building sites, and even floor plans:

> An empirical survey was conducted with architects in Sydney and Hong Kong, and the results show that the selection of surrounding environment for a building and interior layout as proposed by the [non-feng shui] architects generally concurs with the ideal Feng Shui model established more than two thousand years ago. (Mak and Ng 2005, p. 427)

When feng shui advisors go on to advise on the purchase and placement of crystals, mirrors, wind chimes, three-legged gold toads with coins in their mouths, the five elements in each room, and all the other paraphernalia that supposedly brings luck and good fortune – then this suggests that the whole operation is just a piece of creative marketing; that the feng shui operation is a 'dark art'.

Eitel recognised that feng shui site selection and medical guidance goes beyond harmless and benign commonsensical practices:

> Well, if Feng-shui were no more than what our common sense and natural instincts teach us, Chinese Feng-shui would be no such puzzle to us. But the fact is, the Chinese have made Feng-shui a black art, and those that are proficient in this art and derive their livelihood from it, find it to their advantage to make the same mystery of it, with which European alchemists and astrologers used to surround their vagaries. (Eitel 1987, p. 1)

Eitel here articulates a standard criticism: what is good in feng shui practice is merely dressed-up commonsense – construct dwellings and plant crops in proximity to water and not in a wind tunnel or on a mountain top; have living areas orientated to the sun, and sleeping areas away from the sun; avoid having front and rear doors opening in an uninterrupted line; do not have toilets opening into living areas; etc. An advocate for feng shui recently wrote in an American Institute of Architects publication:

> Feng Shui is all about what nurtures a building's occupants and makes them feel comfortable in a space. As architects and designers, we instinctively do a lot of these things. Feng Shui provides the framework and the philosophy to support our instincts. (Knoop 2001)

The argument of this chapter is that all the associated metaphysics, cosmology and ultimately worldview is just hand-waving. As the saying is: 'With the cosmology and two dollars you can ride the subway'. But it is not idle or harmless hand waving, as it opens the cultural door to mystification and worse still, to manipulation by charlatans (Huston 1995). If people get accustomed to believing the fantastic, evidence-free, or evidence-neutral, chi narrative, then what other evidence-free or neutral beliefs might they be prepared to accept? European history if full of episodes of mass hysteria sustained by such gullibility.

1.8.2.2 Chinese Proto-Science and Avoidance of Experiment

Eitel sees feng shui as Chinese natural science, but for him it was a science that did not 'grow up' (Eitel 1987, p. 3). Eitel marks down Confucius and his influential early disciples for not engaging with and correcting the proto feng-shui systems of his age. Many historians and commentators on Confucianism make the same point: Confucius was not engaged by or interested in how the world worked; he had little if any concern with 'natural philosophy' (Chan 1957).

Joseph Needham repeatedly makes this observation (Needham 1963), and follows Eitel in saying that it was the rise of neo-Confucian thought in the late Sung Dynasty (CE 960–1280) that gave a 'modern' scientific direction to Chinese thinking about nature and led to studies in pharmacy, geography, magnetism, mathematics; the direction and groundwork was there, but not the maturation (Needham and Ling 1956, pp. 293–296). He writes:

> The Neo Confucians arrived at what was essentially an organic view of the universe. Composed of matter-energy (*ch'i*) and ordered by the universal principle of organization (*Li*), it was a universe which, though neither created nor governed by any personal deity, was entirely real, and possessed the property of manifesting the highest human values (love, righteousness, sacrifice, etc.) when beings of an integrative level sufficiently high to allow of their appearance, had come into existence. (Needham and Ling 1956, p. 412)

Fifty years after Eitel, Joseph Needham, and many others, debated why Chinese proto-science did not mature in the way that European seventeenth-century did. The became known as 'The Needham Question'. Needham, with his explicit Marxist convictions, looked to 'external' social factors for an answer (Needham 1963). These factors have been long identified: a stratified society where there was a clear separation of manual work and technological experience, from intellectual or philosophical speculation; the primacy given in the Confucian tradition to 'inner' knowledge and personal well-being; the rigid court control of higher knowledge and its dissemination; an in-grained preference for utility rather than understanding, etc.

Eitel had better instincts on this central question, later to be called 'The Needham Question', of: Why was there no scientific revolution in China?[12] Eitel's answer was the lack of an experimental tradition in China. Not 'kitchen' or pragmatic experiments dealing with how to improve production, transport, weapons, cuisine, or manufacturing, but mathematically formulated and controlled scientific experiments with explicit methodological principles. Towards the end of his book, he writes:

> There is one great defect in Feng-shui, which our Western physicists have happily long ago discarded. This is the neglect of an experimental but at the same time critical survey of nature in all its details. (Eitel 1987, p. 69)

Eitel here echoes Kant's famous pronouncement in his *Critique* about the New Science only beginning when Galileo rolled balls down inclined planes and forced Nature to answer to questions that the natural philosopher asked: it was then that 'a light broke upon all students of nature' (Kant 1933, p. 20). Eitel might well have learnt from Kant's commentary during his own doctoral studies at the University of Tübingen. His observation was not far off the mark. Nathan Sivin, the Sinologist and historian of Chinese science has written:

> Still we do not find anything corresponding to Galileo's conviction that physical realities must be isolated from the flux of sensation by measurement (as in experiments) so that physical truth can be made to manifest itself in straightforward quantitative relations. (Sivin 1984, p. 546)

Alexandre Koyré's account of the distinctiveness of the Scientific Revolution is relevant to Eitel's answer to the 'Needham Question'. As Koyré puts it:

> … observation and experience – in the meaning of brute, common-sense observation and experience – had a very small part in the edification of modern science; one could even say that they constituted the chief obstacles that it encountered on its way. … the empiricism of modern science is not *experiential*; it is *experimental*. (Koyré 1968, p. 90)

---

[12] There is a vast literature on the Needham Question, but see at least Jin et al. (1996), Sivin (1984), Lin (1995).

Appraising Eitel's important claim about the centrality of experiment is an occasion not just for historical study, but for scientific/philosophical analysis of what constitutes an experiment. This latter question has been widely and energetically addressed in recent philosophy of science literature.[13]

1.8.2.3 Astronomical Problems for Feng Shui

Leaving aside any scientific or 'metaphysical' problem in translating from motions of the sun and moon to earthly and human affairs, Eitel identifies two major astronomical problems for feng shui theory: the precession of the equinoxes and missing planets.

The Chinese astronomers/astrologers did not know of the precession of the equinoxes from east to west, the effect of which has been to disconnect the astrological signs of the zodiac from their respective constellations. Eitel comments that:

> The Chinese, not knowing of the precession of the equinoxes, are rather perplexed by the discrepancy, but caring less for accuracy and more for ancient tradition, ignore the actual discrepancy, and still represent the twelve signs, not as they appear now, but as they appeared to their ancestors two thousand years ago. (Eitel 1987, p. 11)

This is a matter that at least some contemporary feng shui consultants deal with by simply severing the connection of auspiciousness from the position of star groups in the galaxy.

Eitel identifies another major conceptual and evidential problem: the Chinese recognised only five planets - Jupiter, Venus, Saturn, Mars and Mercury. Given the centrality of these in the whole Chinese cosmological picture, it is easy to understand why Chinese astronomers did not seek to discover new planets. Chinese astronomers may or may not have seen additional planets, but if so, they did not identify them as planets; they would have been regarded as comets, stars or some aberration, just as Uranus was by those who happened upon it from antiquity till William Herschel's identification of it in 1781 (Miner 1998). Similarly, the spectacular 1846 discovery of Neptune by Johann Galle following its mathematically precise prediction by Urbain Le Verrier (Grosser 1962) did not and could not have happened within the Chinese astronomical tradition. These are merely examples of the commonplace observation that culture impacts on the conduct of science, and that recognising and being alert to such a nexus is an important outcome of a good science education.

[13] See at least Hacking (1988) and contributions to Radder (2003).

1.8.2.4 Eitel's Appraisal of Feng Shui and the Educational Task in China

Eitel concludes his exposition by writing that while 2000 years ago the embrace of some of the fundamental ideas of feng shui was understandable and 'rational', but such embrace no longer is. He writes:

> Feng-shui is at present a power in China. It is an essential part of ancestral worship, which national religion, neither Tauism nor Buddhism managed to deprive of its all-pervading presence…Feng-shui is indeed the refined quintessence of Tauistic mysticism, Buddhistic fatalism and Choo-he's materialism, and as such it commands if not the distinct approval yet the secret sympathy of every Chinaman, high or low. (Eitel 1987, pp. 65–66)

He notes that feng shui exponents:

> had studied nature, in a pious and reverential yet in a very superficial and grossly superstitious manner, but which, trusting in the force of a few logical formulae and mystic diagrams, endeavoured to solve all the problems of nature and to explain everything in heaven above and on the earth below with some mathematical categories. The result, of course, is a farrago of nonsense and childish absurdities. (Eitel 1987, p. 69).

Eitel had no hesitation in pointing to the educational project, specifically the science-education project, that was needed in his day:

> The only powerful agent likely to overthrow the almost universal reign of Feng-shui in China I conceive to be the spread of sound views of natural science, the distribution of useful knowledge in China … let correct views be spread regarding those continually interchanging forces of nature, heat, electricity, magnetism, chemical affinity and motion; let these views be set forth in as forcible and attractive, but popular a form as Choo-he employed, and the issue of the whole cannot be doubtful. (Eitel 1987, p. 69)

Although a Lutheran clergyman, he spoke with a voice informed by science and the Enlightenment:

> The fires of science will purge away the geomantic dross, but only that the truth may shine forth in its golden glory. (Eitel 1987, p. 69)

Importantly, he did not underestimate the educational task; it could not be confined just to classrooms:

> Feng-shui is, moreover, so engrafted upon Chinese social life, it has become so firmly intertwined with every possible event of domestic life (birth, marriage, housebuilding, funerals, etc.) that it cannot be uprooted without a complete overthrow and consequent re-organisation of all social forms and habits. (Eitel 1987, p. 65)

Not surprisingly, this contention has drawn down on Eitel the ire of some who have read his work. It is the kind of statement that is put up as 'Exhibit A' to demonstrate cultural insensitivity, Western chauvinism and objectionable scientism and positivism. Notwithstanding all of this, Eitel's recognition of the material embeddedness of feng shui beliefs, and the consequent social and cultural adjustments needed if they were to be abandoned or significantly changed, is both realistic and commendable; nothing is gained by ignoring the difficult personal, cultural and social adjustments that need to be made when modern science is seriously engaged, that is in other than just a utilitarian or technical way. Further, Eitel's view has been independently adopted by many contemporary Chinese scientists, philosophers, educators and cultural critics concerned with the modernization of Chinese culture (Tang 2015a).

1.9 Feng Shui, Education and Modernization of Chinese Culture

In the seventeenth century, China's adoption of Matteo Ricci's European technology, astronomy and mathematics left Confucianism untouched; so too it left the entire Chinese political or imperial system untouched, indeed the latter was strengthened. At the beginning of the twentieth century, a small minority of scholars strove for more radical rapprochement between Chinese culture and modern science. For example, Ch'en Tu-Hsiu [Chen Duxiu] (1879–1942) was an ardent 'public intellectual', political reformist and opponent of obscurantist Confucian philosophy. He was one of thousands who looked to Western thought, especially science, in order to modernise Chinese thinking, and strengthen the society so that the endless humiliations of the late nineteenth and early twentieth centuries visited upon China by the European powers and Japan would not recur.

After living in France and absorbing a good deal of the thinking of the Enlightenment *philosophes*, Ch'en returned in 1910 to China and was, along with prominent teachers at Peking and Tsinghua universities and major publishers in Shanghai, a founding and influential member of the 'New Thought' (sometimes referred to as 'New Culture') movement. Ch'en wanted to modernise Chinese thinking, not just Chinese industry and technology. This 'progressive' movement was locked in conflict with a 'traditional' or 'conservative' one, both vying for influence in the early life of republican China following the collapse of the disastrous Manchu regime (Furth 1983). The New Thought movement launched their own journal *New Youth*. This was edited by Ch'en, and in it he published his own essay 'The French People and Modern Civilization'. He saw that both politics and science contributed to the supremacy of Europe, and that both European liberal, democratic politics and Western science had to be embraced by China; there could be no return to the old ways.

The first issue of *New Youth* contained an editorial essay 'My Solemn Plea to Youth' in which Ch'en wrote:

> Our men of learning do not understand science; thus they make use of *yin-yang* signs and beliefs in the five elements to confuse the world and delude the people and engage in speculations on geomancy …The height of their wondrous illusions is the theory of *ch'I* [primal force] …We will never comprehend this *ch'I* even if we were to search everywhere in the universe. All of these fanciful notions and irrational beliefs can be corrected at their roots by science, because to explain truth by science we must prove everything with fact. Although this is slower than imagination and arbitrary judgment, every progressive step is taken on firm ground. It is different from those flights of fancy which in the end cannot advance one bit. (*New Youth*, 1915, vol.1, p.1. In Kwok 1965, p. 65)

The editorial touches on most of the core scientific, philosophical, cultural and educational issues surrounding feng shui and how it is best treated in a school system. These were momentous issues for China at the beginning of the twentieth century. The same issues recur in all societies and cultures as they ‘come to terms with’ science, and with Enlightenment beliefs especially secularism, liberalism and democracy in politics.

Ch’en’s crusade was supported by Fung Yu-Lan (1895–1990) the noted historian of Chinese philosophy (Fung 1949, 2008). In his much-cited 1922 publication written during the dark depths of Chinese warlord-ism and national humiliation, Fung maintained that:

> What keeps China back is that she has no science. The effect of this fact is not only plain in the material side, but also in the spiritual side, of the present condition of Chinese life. China produced her philosophy [Confucius (551-479 BCE), Mencius (372-289 BCE)] at the same time with, or a little before, the height of Athenian culture. Why did she not produce science at the same time with, or even before, the beginning of modern Europe? (Fung 1922, pp. 237–238)

More recently, Tang Yijie (1927–2014), a prominent Chinese philosopher, well stated the importance of this ‘cultural appraisal’ task:

> If Chinese people want to make contributions to the ‘coexistence of civilizations’ in contemporary human society, they must first know their own culture well, which means they must have a cultural self-consciousness. The so-called cultural-consciousness refers to the fact that people in a certain cultural tradition can give serious consideration or make earnest reexamination of their own culture’s origin, history, characteristics (including both merits and weakness), and its tendency of progress … we must analyze the weak points of our own culture as well to better absorb other cultures’ essences, and to give a modern reinterpretation of Chinese culture, so that it can adapt to the general tendency in the development of modern society. (Tang 2015c, p. 299)

Clearly this task of ‘cultural self-consciousness’, as outlined by the Chinese scholars Chen, Fung, Tang and so many others, is an educational project that requires science-informed historical and philosophical input. It is a task with which *all* societies need to engage. Western and Middle-Eastern societies are as much in need, if not more, of this historical consciousness as Asian societies. The beginnings should be engendered by formal education; responsible science education will contribute to this task in all countries. The more explicitly the HPS dimensions of science are presented in classrooms, then the more fruitful will be such contribution to cultural self-consciousness.

HPS-informed science education can contribute to this cultural task of developing an historical consciousness by showing the historical and philosophical connections between modern science and the Enlightenment tradition.[14] And there are other things that science education can bring to the task: the cultivation of a scientific habit of mind, the appreciation of empirical evidence, coherent and logical thinking, knowledge of basic mechanisms in the natural world.

[14] On this see Matthews (2015, chap. 2).

1.10 Feng Shui and the Chinese Communist Party

In 1940 Mao Tse-Tung declared for science and against superstition, including feng shui, saying:

> The culture of this New Democracy is scientific. It opposes all feudal and superstitious thought; it advocates practical realism, objective truth, and the union of theory and practice. From this point of view, the scientific thought of the Chinese proletariat, along with the comparatively progressive material monists and natural scientists of the capitalist class, must unite to oppose imperialism, feudalism, and superstition; [they] must not ally themselves with any reactionary idealism. (*Selected Works*, vol.2, p. 700; in Kwok 1965, p. 19)

When the Chinese Communist Party came to power in 1949 it outlawed feng shui as a form of backward superstition and as being incompatible with Marxist theory and its associated materialist ontology. The Party said feng shui was one of the 'Four Olds' (Shapiro 2001). The clamp down on feng shui was tightened during the Cultural Revolution. Mao's efforts to outlaw and ban the practice, and to systematically refute the associated cosmological beliefs as being incompatible with Marxist dialectics and materialism, were Canute-like in their effect: the feng shui tide kept rising in China.

Part of the reason for this was that Mao's embrace of science was the embrace of a stunted science; a purely technological science that ignored the wider social and philosophical implications of science, much less embraced its connection with the Enlightenment's critical and 'Open Society' traditions. Chairman Mao's Education Directive of July 11, 1968, said that, reluctantly:

> It is still necessary to have universities; here I refer mainly to colleges of science and engineering. However, it is essential to shorten the length of schooling, revolutionize education, put proletarian politics in command and take the road of the Shanghai Machine Tools Plant in training technicians from among the workers. Students should be selected from among workers and peasants with practical experience, and they should turn to production after a few years' study. (Bloembergen 1980, p. 104).

Because the university curriculum was closely tied to practical outcomes, there was no course in General Physics, rather physics was divided into subspecialties – lasers, acoustics, magnetism, radio-physics, etc. – once admitted to a specialty in first year, students could only with great difficulty change. During this period, China produced hundreds of thousands of science graduates who had no inkling of the tradition and culture of modern science, much less had cultivated a scientific habit of mind, or a social-historical critical facility.[15] Students graduated with what amounted to bachelor degrees in radios, or internal-combustion engines. They were more technicians than scientists; little in their education would prepare them for intelligent engagement with feng shui or party ideology.[16]

---

[15] On this see Bloembergen (1980). As with other countries, there are blind-spots or 'no-go' areas in Chinese historical studies. For example, serious appraisal of Mao, and the devastation he unleashed on China, is simply not included in the curriculum.

[16] This 'stunted worldview-free' science is favoured by proponents of 'border-crossing' in multicultural science education (Aikenhead 1996). Such proponents maintain that indigenous commu-

The first ever Chinese national science congress was held in March 1978 after the Party repudiated and denounced the Gang of Four and its anti-intellectualism, but there was not, of course, any denunciation of Chairman Mao. Vice-Premier Deng Xiaoping's four modernizations – of agriculture, industry, defense, and science and technology - were announced as Party policy and the 6000 attendees were ordered to contribute to the modernization of science.[17] A broader science training was envisaged, but there were limits. Fang Yi, a politburo member, future Vice-Premier and President of the Chinese Academy of Science, in his speech to the congress said:

> We actively advocate the study of Marxist philosophy by scientific and technical workers, and we should encourage and help them to do so. It is necessary to hold different kinds of forums regularly, begin publishing journals on the dialectics of nature, carry out research on the history of natural science, and encourage scientific and technical personnel to guide their scientific research with Marxist philosophical concepts. (Orleans 1980, p. 554)

Fang's programme has continued to the present day, with 'Dialectics of Nature' being a compulsory course for all science graduate programmes (Gong 1996; Guo 2014). It is little wonder that many Chinese intellectuals lament that a fifth modernization, namely the modernization of culture, was not added to Deng's four modernizations. But this would have deleterious consequences for Communist Party rule.

1.11 Teaching About Energy and Appraising Feng Shui

One obvious and non-controversial way to raise issues about feng shui in science classes is to do so when teaching units on energy. Throughout the world at all educational levels - elementary, secondary and college - energy is a ubiquitous topic in science programmes. The study of energy is one of the core requirements in the English (UK) school science programme where students are expected to detail different sources of energy and know how different cultures utilize these sources. Energy is one of the core 'cross cutting concepts' in the USA *Next Generation Science Standards* (NRC 2013).[18]

This ubiquity is deserved because energy is the central conceptual component of modern science – all modern science, not just physics. Mario Bunge observed: 'All the sciences that study concrete or material things, from physics to biology to social science, use one or more concepts of energy' (Bunge 2000, p. 458). Energy is a property of all existent things; hence it is universal. But it does not exist apart from

nities should be taught enough science to cope with modern technology, but not use it to appraise their own worldviews or metaphysical commitments.

[17] Deng Xiaoping and Fang Yi's congress addresses are reproduced in Orleans (1980, pp. 535–556).

[18] Papers presented at an international conference to link research to the teaching of energy in the NGSS can be seen in Chen et al. (2014). See also chap. 9 of this anthology.

things of which it is a property; there is no ‘free-floating’ energy. Bunge is relaxed about calling energy a metaphysical concept:

> Because it is ubiquitous, the concept of energy must be philosophical and, in particular, metaphysical (ontological). (Bunge 2000, p. 458)

For Bunge, and all competent philosophers, metaphysics does not license obscurantism, incoherence or contradiction. Richard Feynman famously said in his *Lectures in Physics* that:

> It is important to realize that in physics today, we have no knowledge of what energy *is*. We do not have a picture that energy comes in little blobs of a definite amount. It is not that way. However, there are formulas for calculating some numerical quantity, and when we add it all together it gives “28”—always the same number. It is an abstract thing in that it does not tell us the mechanism or the *reasons* for the various formulas. (Feynman 1963, Lect.4, sect. 4.1, p. 2)

Although he modestly says that he does not know what energy is, he is prepared to defend the claim that whatever it is, it is conserved. And far from Feynman’s lecture legitimating all alternatives to orthodox scientific understanding of energy, he is prepared to say that psychoanalysis is not a science and that witchdoctors’ recourse to spirits as the cause of disease likewise marks them as non-scientific (Feynman 1963, lect. 3, sect. 3.6). As long as chi remains in the heavens, then its violation, or otherwise, of energy conservation cannot be ascertained. But as soon as chi engages with worldly processes, then it enters terrestrial energy chains and can be shown to violate the conservation law if any of its putative effects are real.

In the USA, the Department of Energy (DoE) produced an educational guide that specifies an ‘energy literate’ person has:

> An understanding of the nature and role of energy in the universe and in our lives. Energy literacy is also the ability to apply this understanding to answer questions and solve problems. (DoE 2012, p. 4)

The US Department further elaborates that such a person ‘Can assess the credibility of information about energy’.

Given the centrality of ‘energy’ in feng shui discourse and practice, and given the wide influence and impact of feng shui in Asian and now Western culture, these DoE objectives can assuredly be advanced by explicit treatment of feng shui in science classes. The DoE guide means that students should be able to assess the credibility of feng shui energy claims (and indeed any other popular claims about energy creation or conservation). If daily feng shui forecasts are on the nightly news, then asking a class to assess their credibility is hardly an outside imposition on the class, or a pandering to a teacher’s proclivities.

1.12 Scientific Testing of Chi Claims

Pleasingly there seem to be some opportunities for clear-cut scientific tests for the putative powers of chi. Dr. Yan Xin, a medical researcher from the Chinese Chi Research Centre, who has worked in major Western and Chinese universities, commendably spells out the power of chi in a testable manner (Yan 2015). As Karl Popper would say, he bravely puts his theory's neck on the experimental block:

> the mind power or *Qi* emitted by a trained Qigong master can influence or change the molecular structure of many test samples, including those of DNA and RNA, even if these test samples are 6 to 2,000 kilometers away from the master. *Qi* can also effect the half-life of radioactive isotopes and the polarization plane of a beam of light as emitted from a Helium-Neon laser.[19]

At first, and even last, reading these are stunning claims; they certainly have the patina of science. As Yan Xin's followers maintain: 'His discoveries are changing the way modern science is viewed, and challenging many of its assumptions' (ibid). But Dr. Xin then retreats and takes the theory's head off the block:

> Currently, the essential qualities of qigong and qi are difficult to study in a detailed, qualitative, and quantitative manner. (ibid)

Pleasingly serious scientific research journals require studies to be done in a 'detailed, qualitative, and quantitative' manner and so set a high bar for publication. So far, it seems, that feng shui 'research' has not met the standards of any reputable scientific journal; no reference appears in physics journals. But gullible people, with minimal science literacy, read such claims and believe that modern science has so changed and has endorsed such nonsense. But modern science is simply incompatible with the truth of these claims; they could never find outlet in any serious science research journal.

Another colleague, Dr. Hui Lin, also of the Chinese Chi Research Centre offers the following striking example of chi power:

> Consider a simple experiment on qigong potential. In this experiment people used their qi to shake pills out of a sealed bottle. However, the intermediate process was undetectable by any available means. The pills passed through the bottle (analogous to conducted experiments in which a person passes through a solid wall), even though the bottle is completely sealed and intact, without any possibility of tampering.

Accepting at face value the results, he concludes that:

> This demonstrates the probable existence of a form of energy associated with qi which transcends the three or four [gravitational, electromagnetic, strong and weak interaction] fundamental forces.

This all sounds very scientific and certainly would cause a revision in our understanding of science and of the world picture that science has given us. But in Hui Lin's 'experiment', no independent witness to such 'transportation' is noted; and no replication study is reported. Independent observation and replication should be the

[19] See: www.item-bioenergy.com/infocenter/chinesechiresearch.doc

beginning of any effort to bring these 'truly remarkable results' into the scientific fold.[20] They should be among the first things that any scientifically literate student or adult asks of the remarkable experiment. Their absence is a powerful indicator of the whole feng shui practice being pseudoscientific.

After 200 years of modern scientific study of energy,[21] with pressing contemporary universal concern with clean energy production and use, and with numerous major international energy summits and conferences, it is noteworthy that feng shui energy is yet to be indentified and convincingly measured in any reputable laboratory. There are many putative such measures, providing 'convincing' evidence for the efficacy of chi, but as with the above cases from the China Chi Research Centre, they do not bear close scrutiny.

What constitutes 'close scrutiny' is something that can be taught in science classes when teachers have a modicum of HPS competence and interest. Students can read the texts, and follow the experimental footsteps of Galileo, Newton, Huygens, Priestley, Darwin, Rutherford, and so many others, and see and appreciate the difference between close scrutiny, careful measurement, appraisal of alternative hypotheses, and the lazy uncritical holding of original and perhaps prejudicial opinions.

1.13 Feng Shui as Pseudoscience

Belief systems, and associated practices, can usefully be categorized as: Science (either mature or proto-science), Pseudoscience (non-science that claims to be science) and Non-science (History, Art, Theology, Philosophy, etc.). Such classification does depend upon adequate demarcation criteria, but these do not require any timeless essentialism, and they can and have changed over time as scientific inquiry matures and takes new forms.[22] Further, membership of a category is not cut and dried, it is more a matter of family resemblance; there are clusters of criteria that mark out the categories, these can change over time, and not all boxes need be ticked,

Efforts to distinguish science from non-science, the original 'demarcation problem', have been pursued since at least David Hume's time when in his *Inquiry* he commented:

> When we entertain, therefore, any suspicion that a philosophical term is employed without any meaning or idea (as is but too frequent), we need but enquire, *from what impression is that supposed idea derived?* And if it be impossible to assign any, this will serve to confirm our suspicion. (Hume 1902, p. 22, emphasis in original)

---

[20] The magician, James Randi, has rendered a great public service by replicating, exposing and debunking these sorts of claims (Randi 1987, 1995).

[21] See at least Coopersmith (2010) and Harman (1982).

[22] There is an enormous amount of philosophical discussion on the 'demarcation problem'. See at least Butts (1993), (Hansson 2009, 2013), Mahner (2007, 2013), Nickles (2013) and Pigliucci (2013).

Hume was enunciating his empiricism and using the grounding in sensation as a way of separating 'sensible' ideas from the wide class of others. Ernst Mach took Hume's point seriously and, with recourse to his philosophical phenomenalism argued that a whole raft of central scientific concepts – mass, force, absolute space, absolute time, atom, molecule – were not scientific as they went beyond their sensory anchors, or the observation statements that grounded them (Mach 1992). He famously said that he would 'leave the Church of Physics' if belief in atoms was required for its membership (Blackmore 1989).

Karl Popper acknowledged the force of Mach's critique, but rather than accept orthodox science as unscientific, he proposed a new demarcation of science from non-science, namely Falsificationism or Testability, maintaining that:

> A system is to be considered as scientific only if it makes assertions which may clash with observations; and a system is, in fact, tested by attempts to produce such clashes, that is to say by attempts to refute it. (Popper 1963, p. 256)

A great deal of late twentieth-century philosophy of science has been taken up with problems occasioned by using testability as a demarcation criterion for science, and with efforts to find other more adequate criteria. Willard Quine, Thomas Kuhn, Imre Lakatos, Paul Feyerabend and Paul Thagard all contributed to this debate.[23] Lakatos thought that his 'methodology of scientific research programmes' did provide a warranted demarcation in the way that Popper and Kuhn's had failed to do (Lakatos 1970). Further this was important because:

> … the problem of demarcation between science and pseudoscience is not a pseudo-problem of armchair philosophers: it has grave ethical and political implications. (Lakatos 1978, p. 7)

The mushrooming, internationalizing, billion-dollar feng shui industry is an example of the ethical, political and cultural consequences of failing to identify pseudoscience, or saying that such identification is impossible, to which Lakatos points. Being able to robustly identify feng shui as pseudoscience might put some brake on its spread and impact, it might redirect people's monies to effective treatments, in some jurisdictions it might enable conviction for false advertising, etc. And beyond this, defense of such identification can engage citizens in careful analysis of an important philosophical point that is central to understanding the nature of science.

Carl Hempel usefully offered not so much a singular demarcation criterion, but rather a list of seven *desiderata* that identified good science, or specifically good scientific theories, among which are:

- A theory should yield precise, preferably quantitative, predictions.
- It should be accurate in the sense that testable consequences derivable from it should be in good agreement with the results of experimental tests.
- It should be consistent both internally and with currently accepted theories in neighboring fields.
- It should have broad scope.

[23] For an outline of the arguments and literature, see Ladyman (2013), chap. 3).

- It should predict phenomena that are novel in the sense of not having been known or taken into account when the theory was formulated.
- It should be simple.
- It should be fruitful. (Hempel 1983, pp. 87–88; author formatting added)

This account usefully employs a number of criteria to distinguish good theories from not-so-good or poor theories. Indeed, 'marks out of five' can be given to theories on the basis of how well they meet each criterion, with a maximum possible score of thirty-five. Then discussion can occur about 'cut-off' marks for separating good from poor theories. Here poor theories can be improved, they can raise their mark by attending to one or other deficiency.

It is unfortunate that Hempel conflates 'science' with 'theories'. Good theories, as Hempel characterizes them, are the expected outcome and indicator of good science; but science as an organized, structured, historical-sociological entity, needs further characterization beyond what suffices for good theory. Extra ontological, methodological and sociological criteria are required; the more so in order to separate science from pseudoscience.[24] For a research or scholarly group to be called a scientific group, or for it to be pursuing a scientific practice, it needs have the following characteristics:

- It should reliably produce a 'quota' of good scientific theories as characterized above.
- It needs to seek new knowledge, to do research; not be ossified, stand still, and repeat extant knowledge.
- It should be constituted as a research community pursuing cognitive goals and committed to finding out new things about the natural and/or social worlds; not just a community sharing beliefs, inquiring into texts or formulating legislative laws.
- Its members need be trained or certified in such cognitive inquiry; science can be advanced by lay-people, but if no or few members of the community are suitably trained, then the community falls short of being a scientific community;
- It should appeal only to ontologically stable entities in its explanations and theorizing. Reference to 'here today, gone tomorrow' entities, or entities that come in and out of existence depending on who is thinking about them, diminish the scientific status of theories and communities that propose them.
- It needs be committed to at least pragmatic methodological naturalism as the basis for evidence collection and theory appraisal; appeals to political, ideological or religious authority is simply not allowed, nor is reference to divine scripture or revelation.

Methodological naturalism, in the final criterion, is not methodological materialism. The latter characterized the Mechanical Worldview of the seventeenth and eighteenth centuries (Schofield 1970), but with the progress of nineteenth and twentieth century science, where there was recourse to stable, yet non-material, explana-

[24] See Bunge (1991).

tory and causal entities (non-contact forces, fields, radiation, gravitational waves, etc.) materialist ontology became a hindrance rather than an asset for science; and such novel non-material entities became 'naturalised'.

One option is to claim that upholding methodological naturalism is a defining feature of a scientific community of inquiry (Mahner 2012). This does have an inbuilt conservatism as only currently acknowledged 'natural' entities can feature in the research of a putative scientific group. A more relaxed option is to take 'pragmatic methodological naturalism' as a defining characteristic of a scientific community. Here the community tries to go as far as it can with extant naturalized entities, but recourse to new entities is not ruled out provided efforts are then made to naturalise them; that is, to show that they meet all the accepted grounds for incorporation into science (Fishman and Boudry 2013).

Much is rightly made of the under-determination of scientific theory by evidence - the Duhem-Quine thesis (Harding 1976; Weinert 1995). More specifically there is serious argument, initiated by Ernst Mach in the late nineteenth century, about premature realist inferences to the reality of hypothetical constructs or entities in explanatory scientific theories (Matthews 2015, chap. 9). There are detailed philosophical and scientific debates about the ontological status of phlogiston, caloric, atoms, genes, fields, electron shells, forces, and so on. Nothing comparable occurs in the uncritical, unreflective feng shui move from rural farming practice or architectural commonsense to the putative reality of chi. The mere juxtaposition of debates about realism in science and in feng shui can illustrate important features of science and of pseudoscience.

Larry Laudan, in a much commented-upon paper hoped to bring this discussion to an end with his claim that the demarcation quest was hopelessly contentious:

> … it is probably fair to say that there is no demarcation line between science and non-science, or between science and pseudo-science, which would win assent from a majority of philosophers. (Laudan 1996, p. 211)

And further that the efforts were misdirected because they:

> managed to conflate two quite distinct questions: What makes a belief well founded (or heuristically fertile)? And what makes a belief scientific? (Laudan 1996, p. 222)

He concluded his paper with the admonition:

> If we would stand up and be counted on the side of reason, we ought to drop terms like 'pseudo-science' and 'unscientific' from our vocabulary; they are just hollow phrases which do only emotive work for us. (Laudan 1996, p. 222)

Laudan's philosophical argument gained the assent of the majority of philosophers of science, not just the more general scholarly or educational constructivist community who could be expected to readily embraced it. Constructivists were very happy to hear prominent philosophers saying that 'everything is science; it is only politics, ideology, or culture that makes distinctions for their own purposes'. But Laudan's obituary for demarcation was premature; many have found philosophical life in the supposed corpse.[25] Thus there is no overwhelming philosophical requirement to abandon the tripartite classification of Science-Pseudoscience-Non-science.

It helps the argument of this chapter to focus on just the first distinction, namely Science-Pseudoscience rather than the wider task of separating both from Non-sciences such as Art, History, Mathematics, Theology and so on. How these domains have justifiable warrants for their claims is a matter for separate investigation. Different philosophical, sociological and political indicators or markers of pseudoscience have been advanced. Sven Hansson provided one such list whereby a corpus of belief and practice can be judged pseudoscientific in as much as:

- There is overdependence on authority figures.
- Unrepeatable experiments are too frequently adduced.
- Data selectivity, or cherry-picking of evidence is too common.
- There is an unwillingness to seriously test claims and predictions.
- Confirmation bias is endemic and disconfirmation is neither sought nor recognized.
- Some explanations are changed without systematic consideration. (Hansson 2009)

And when:

- They make claims about events and mechanisms in the natural world.
- The claims cannot be epistemically warranted, yet effort is made to show their scientificity.
- They too easily resort to auxiliary hypotheses to insulate claims from empirical refutation. (Hansson 2009)

A further characteristic that can be added to this list, is:

- The practice makes scientific claims, but refuses to engage with the scientific community (publishing in research journals, presenting at research conferences), whose status it is claiming.

Although there is a certain variation of feng shui beliefs and practices, the feng shui ‘family’ ticks all the above ‘boxes’.

The central feng shui ontological entity, chi - its *sine qua non* as Stephen Field rightly called it – does not appear in any reputable physics research journal or book. Chi is not mentioned anywhere in the hugely-funded international search for new energy, renewable energy or clean energy. The *Science in Contemporary China* handbook (Orleans 1980) has chapters on all the Chinese natural, social and applied sciences, including biomedical sciences, but no chapter on either chi or feng shui. The only mention of either in the entire work is in discussion of acupuncture where the ‘meridian’ theory of freeing vital energy pathways by inserting needles into various of the 600+ meridian intersections, is listed as the original explanation for the efficacy of acupuncture; but this is then passed over in favour of contemporary,

[25] See at least: Bunge (1991, 2011), Butts (1993), Derksen (1993), Ladyman (2013), Mahner (2007, 2013), Pigliucci (2013) and the 23 contributions to Pigliucci and Boudry (2013).

routine physiological or psychological accounts of the highly-debated effects of acupuncture. Myron Wegman, the author of the Biomedical Research chapter in the above handbook, observes that: 'a classic weakness …of most Chinese research on therapy is the absence of true controls, essential if one is to draw secure conclusions about the efficacy of a particular treatment' (Wegman 1980, p. 273). He notes that this is a particular problem for acupuncture research because the illnesses 'cured' are often ones where there is a high portion of spontaneous recovery or remission.[26]

To say, as Ken Tobin above does, that the feng shui industry is engaged in and informed by 'unorthodox' or 'alternative' science is too generous. Leaving aside philosophical considerations, on just sociological or externalist grounds alone, chi-based feng shui is not a science. It does not meet the criteria of 'playing the game'; practitioners might be playing *a* game, but it is not *the* science game. The situation is akin to a local rugby team saying they are playing 'alternative baseball' or 'unorthodox baseball'. For the latter names to be meaningful, there has to be an overlap in key elements with baseball. And the latter cannot be called 'poor rugby' as that suggests that by incremental improvements baseball could become rugby. It cannot. Rugby is an alternate to baseball, it is not alternative or unorthodox baseball. Similarly science and feng shui are not on a continuum; the difference is not like that between full-strength and lite beer.

Efforts to place science and feng shui on a continuum do not adequately capture the unfortunate cultural, commercial and personal realities of feng shui. For example, one of the hundreds of newly arrived feng shui consultants in Sydney has in 2016 advertised for business asserting that:

> As a descendant of the Founding Father of Feng Shui – King Wen**,** highly sought after by scores of billionaire customers, with 30 years of experience, Master Feng, the world's only Feng Shui Master who has the gift of SEEING Feng Shui energies, will help you get rid of: Bad Luck, Achieve Success, Health, Wealth and Happiness.[27]

Not only does King Wen 'see' energy but he has 'x-ray vision' that detects ulcers, slipped discs and a whole range of ailments. And he can predict people's futures. All of this comes at a price. He claims his costly 3-day courses 'eliminates confusion caused from different conflicting Feng Shui ideologies'. Full credit to King Wen that he acknowledges that other feng shui systems are ideologies. Although he does not elaborate his own meaning of 'ideology', doubtless whatever this account is, it is a reasonable expectation that it will apply to his own interpretation of feng shui.

---

[26] There is a vast literature on the contentious Western interpretation of the success of Chinese traditional medicine, including acupuncture. See at least Porkert (1982).

[27] See http://www.masterfeng.com/consultations.html

1.14 Conclusion

Feng shui theorists and consultants are practicing something that superficially appears like science and is infused with scientific terminology – witness the title of the recent book *Scientific Feng Shui for the Built Environment* (Mak and So 2015) - but it is not science. The key elements of science, both content and methodology, are missing:

- There is no tradition of controlled and reproducible experiment.
- There is no recognition of the problematic recourse to *ad hoc* rescuing of failed hypotheses.
- There is a dramatic inconsistency with the core of established scientific knowledge, most especially the conservation of energy postulate.
- There is no participation in the established, peer-reviewed, scientific research community and its journals.
- There is altogether unwarranted dependence upon individual or sectarian interpretation of basic feng shui principles; there are hundreds of different feng shui 'schools' each with masters but no unified canon.
- Finally, there is a radical disjunct between the law-governed, causally-deterministic worldview of science and the chaotic, idiosyncratic 'fortune-telling', 'auspicious times' worldview of feng shui. The latter is only imaginable if the fundamental laws of causation for macro objects are jettisoned; and if that happens then science is also abandoned. Whatever legitimate debate there is about causality at the micro or sub-atomic level (Bunge 1982), there is none at the macro-level where feng shui interventions, and chi-caused events supposedly take place.

In as much as the modernization of thought depends upon its reconciliation with science, then feng shui ideology is a barrier to modernization of thought in all cultures where it has taken root. Further it is manifest that feng shui practice has been overtaken by charlatans and fraudsters; these are not absent from science, but the scientific community can identify them, and call them out.[28] It is not at all clear how 'fake' or fraudulent feng shui practitioners can be called out. The task is comparable to identifying and condemning heresy in religious traditions. The designation of feng shui as 'pseudoscience' well captures the differences with science, and alerts everyone to the omnipresence of fraud.

All institutions, belief systems and ideologies benefit from historical study; from understanding themselves in an historical sequence and context. All the major religions have gained from developing such perspectives. The change, and arguably corruption, of religious, political and more generally, ideological institutions and beliefs over time is a common historical reality. Judaism, Islam, Christianity, Hinduism, Marxism and Liberalism have all had to identify what is genuine 'devel-

[28] On fraud in contemporary science, see at least Bell (1992), Oreskes and Conway (2010), and Park (2000).

opment', what is 'corruption' and what is ossified 'fundamentalism' in the historical development of their traditions. This is abundantly true of science: an historical understanding of science reveals essential features of its dependence on culture, of its connection with philosophy and metaphysics, of its changing methodology and canons of proof, and much more.

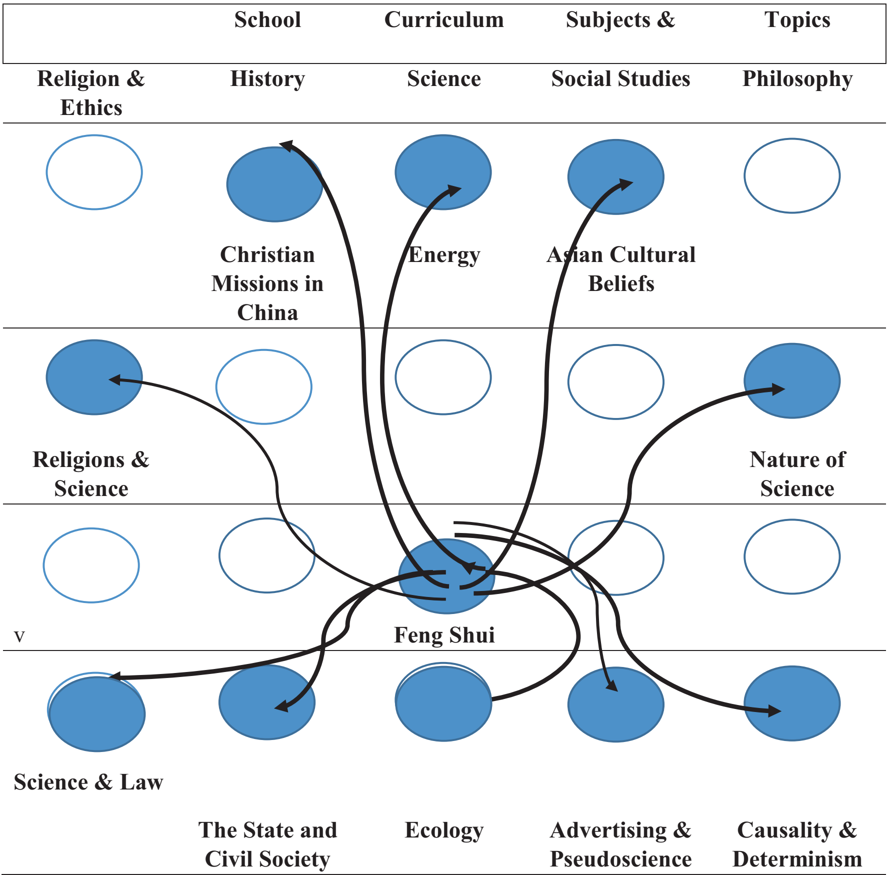
Famously Thomas Kuhn said that it was his unplanned teaching of a history of science course at Harvard University that opened his eyes to a real understanding of science (Kuhn 1970, p.v). A cursory historical study shows that astrology and alchemy were once part of mainstream Western science, with Isaac Newton being a serious practitioner of both into the early eighteenth century. Natural theology was part of the birth of modern science and remained undisturbed at its core up to the time of Darwin and beyond.[29] But science has progressively developed, and its knowledge of the constituents and mechanisms of the world have refined. Astrology, alchemy and natural theology are no longer part of science. This has been an outcome of science's commitment to, minimally, pragmatic methodological naturalism.[30] The same standard applied to feng shui takes it out of the scientific family.

Students can benefit from applying the same historical-philosophical analysis to feng shui, and this can be part of its examination in science classes. Across the spectrum of features of science – experimentation, authority, prediction, precision, mathematisation, idealisation, coherence, testimony (Matthews 2011) - feng shui can be juxtaposed with science, and similarities and differences drawn out. Feng shui belief in society and classrooms presents not so much a problem for teachers as an opportunity (Martin 1994). Its considered and informed examination is a way for students to learn about the nature of science (Turgut 2011) and other important social processes – marketing, determiners of belief, and so on. It will be apparent that feng shui violates all constitutive and procedural components of science. Such learning can be science education's contribution to the cultural health of society. The latter is inversely related to the degree of gullibility, credulity, superstition and embrace of careless unwarranted beliefs in society (Kaminer 1999; Lindeman and Aarnio 2007; Shermer 2002). With better organised curricula, perhaps history, social studies, philosophy and cultural studies departments can cooperatively contribute to the considered examination of feng shui.

A co-ordinated, cross-disciplinary approach to the inclusion of feng shui in a curriculum might look like the following table. Such subject co-ordination fits well the aspirations of integrated STEM-Humanities, or STEAM education programmes (Kim 2014).

[29] Of many works on the theological background of early modern science see Hooykaas (1972, 1999), Mascall (1956), and contributions to Lindberg and Numbers (1986).

[30] On scientific naturalism, and religious responses to it, see Drees (1996, chap. 5).



References

American Association for the Advancement of Science (AAAS). (1989). *Project 2061: Science for All Americans*, AAAS, Washington, DC. Also published by Oxford University Press, 1990.

Aczel, A. D. (2001). *The riddle of the compass: The invention that changed the world*. Orlando: Harcourt.

Alexander, C. (1987). *A timeless way of building*. New York: Oxford University Press.

Bell, R. (1992). *Impure science: Fraud, compromise and political influence in scientific research*. New York: Wiley.

Blackmore, J. T. (1989). Ernst Mach leaves "the Church of Physics". *British Journal for Philosophy of Science, 40*, 519–540.

Bloembergen, N. (1980). Physics. In L. A. Orleans (Ed.), *Science in contemporary China* (pp. 85–109). Stanford: Stanford University Press.

Bruun, O. (2008). *An introduction to Feng Shui*. Cambridge: Cambridge University Press.

Bruun, O., & Kalland, A. (Eds.). (1995). *Asian perceptions of nature – A critical approach*. London: Curzon Press.
Bunge, M. (1982). The revival of causality. In G. Floistad (ed.), *Contemporary philosophy,* vol. 2, (pp. 133–155) The Hague: Martinus Nijhoff, Reproduced in Martin Mahner (Ed.), *Selected essays of Mario Bunge*, (2001), (pp. 57–74) Amherst: Prometheus Books.
Bunge, M. (1991). What is science? Does it matter to distinguish it from pseudoscience? *New Ideas in Psychology, 9*, 245–283.
Bunge, M. (2000). Energy: Between physics and metaphysics. *Science & Education, 9*(5), 457–461.
Bunge, M. (2011). Knowledge: Genuine and bogus. *Science & Education, 20*(5–6), 411–438.
Capra, F. (1984). *The Tao of Physics, 2nd revised edition of 1975 original*. New York: Bantam Books.
Chan, W.-T. (1957). Neo-Confucianism and Chinese scientific thought. *Philosophy East and West, 6*(4), 309–332.
Chan, W.-T. (1963). *A source book in Chinese philosophy*. Princeton: Princeton University Press.
Chan, W.-T. (1967). *Chinese philosophy, 1949–1963: An annotated bibliography of mainland China publications*. Honolulu: East-West Center Press.
Chen, X., & Wu, J. (2009). Sustainable landscape architecture: Implications of the Chinese philosophy of 'unity of man with nature' and beyond. *Landscape Ecology, 24*(8), 1015–1026.
Chen, R. F., Eisenkraft, A., Fortus, D., Krajcik, J., Neumann, K., Nordine, J., & Scheff, A. (Eds.). (2014). *Teaching and learning of energy in K-12 education*. Dordrecht: Springer.
Coopersmith, J. (2010). *Energy, the subtle concept: The discovery of Feynman's blocks from Leibniz to Einstein*. Oxford: Oxford University Press.
Cronin, V. (1955). *The wise man from the west: Matteo Ricci and his Mission to China*. New York: Harper Collins.
Dainian, F., & Cohen, R. S. (Eds.). (1996). *Chinese studies in the history and philosophy of science and technology*. Dordrecht: Kluwer Academic Publishers.
Department of Energy (DoE) USA. (2012). *Energy literacy: Essential principles an fundamental concepts for energy education*. Washington, DC: US Department of Energy.
d'Elia, P.M. (1960). *Galileo in China. Relations through the Roman College between Galileo and the Jesuit Scientist-Missionaries (1610–1640)*, (S. Rufus, Trans.). Cambridge: Harvard University Press.
Derksen, A. A. (1993). The seven sins of pseudoscience. *Journal for General Philosophy of Science, 24*, 17–42.
Drees, W. B. (1996). *Religion, science and naturalism*. Cambridge: Cambridge University Press.
Eitel, E. J. (1873). *Buddhism: Its historical, theoretical and popular aspects*. London: Trübner &.
Eitel, E.J. (1873/1987). *Feng Shui: The rudiments of natural science in China*, Lane, Crawford & Co., Hong Kong, Graham Brash, Singapore.
Eitel, E.J. (1895/1983). *Europe in China: A History of Hong Kong*, (ed. H.J. Lethbridge) Hong Kong: Oxford University Press.
Emmons, C. F. (1992). Hong Kong's *Feng Shui:* Popular magic in a modern urban setting. *The Journal of Popular Culture, 26*(1), 39–50.
Feynman, R. P. (1963). *The Feynman Lectures on physics, vol. I: Mainly mechanics, radiation, and heat*. Pasadena: California Institute of Technology.
Fishman, Y. I. (2009). Can science test supernatural worldviews? *Science & Education, 18*(6–7), 813–837.
Fishman, Y. I., & Boudry, M. (2013). Does science presuppose naturalism (or, indeed, anything at all)? *Science & Education, 22*(5), 921–949.
Fung, Y.-L. (1922). Why China has no science – An interpretation of the history and consequences of Chinese philosophy. *International Journal of Ethics, 32*(3), 237–263.
Fung, Yu-Lan. (1947). *The spirit of Chinese philosophy* (H. E. Rughes, Trans.). London: Kegan Paul.

Fung, Yu-Lan. (1949. *History of Chinese philosophy* (D. Bodde, Trans.). Princeton: Princeton University Press.
Fung, Y.-L. (2008). *Selected philosophical writings of Feng Yu-Lan*. Beijing: Foreign Languages Press.
Furth, C. (1983). Intellectual change: From the reform movement to the may fourth movement, 1895–1920. In J. K. Fairbank (Ed.), *Republican China 1912–1949* (pp. 322–405). Cambridge: Cambridge University Press.
Gallagher, W. (1993). *The power of place: How our surroundings shape our thoughts, emotions & actions*. New York: Simon & Schuster.
Gardner, M. (1981). Science: Good, bad and bogus*: A skeptical look at extraordinary claiims*. Buffalo: Prometheus Books.
Gong, Y. (1996). *Dialectics of nature in China*. Beijing: Beijing University Press.
Grim, P. (Ed.). (1990). *Philosophy of science and the occult*. Albany: State University of New York Press.
Grosser, M. (1962). *The discovery of Neptune*. New York: Dover.
Guo, P. (2001). *The Zangshu, or Book of Burial* (S. Field, Trans.). web source. [original ≈ 300BCE].
Guo, P. (2004). *The Zangshu, or Book of Burial* (J. Zhang, Trans.). Lewiston: Edwin Mellen Press. [original ≈ 300BCE].
Guo, Y. (2014). The philosophy of science and technology in China: Political and ideological influences. *Science & Education, 23*(9), 1835–1844.
Hacking, I. (1988). Philosophers of experiment. In A. Fine & J. Leplin (Eds.), *PSA 1988* (Vol. 2, pp. 147–156).
Han, K.-T. (2001). Traditional Chinese site selection-Feng Shui: An evolutionary/ecological perspective. *Journal of Cultural Geography, 19*(1), 75–96.
Hansson, S. O. (2009). Cutting the Gordian knot of demarcation. *International Studies in the Philosophy of Science, 23*, 237–243.
Hansson, S. O. (2013). Defining pseudoscience and science. In M. Pigliccci & M. Boudry (Eds.), *Philosophy of pseudoscience: Reconsidering the demarcation problem* (pp. 61–77). Chicago: University of Chicago Press.
Harding, S. G. (1976). *Can theories be refuted? Essays on the Duhem-Quine thesis*. Dordrecht: Reidel.
Harman, P. M. (1982). *Energy, force and matter: The conceptual development of nineteenth-century physics*. Cambridge: Cambridge University Press.
Hempel, C. G. (1983). Valuation and objectivity in science. In R. S. Cohen & L. Laudan (Eds.), *Physics, philosophy and psychoanalysis: Essays in honor of Adolf Grünbaum* (pp. 111–127). Dordrecht: Reidel.
Henderson, J. R. (2010). Cosmology and concepts of nature in ancient China. In H. U. Vogel & G. Dux (Eds.), *Concepts of nature: A Chinese-European cross-cultural perspective* (pp. 198–218). Leiden: Brill.
Hooykaas, R. (1972). *Religion and the rise of modern science*. Edinburgh: Scottish Academic Press.
Hooykaas, R. (1999). *Fact, faith and fiction in the development of science*. Dordrecht: Kluwer Academic Publishers.
Hsia, P.-C. R. (2012). *A Jesuit in the Forbidden City: Matteo Ricci 1552–1610*. Oxford: Oxford University Press.
Hsu, S.-T. (2003). *Yin & Yang of love: Feng Shui for Relationships*. St. Paul: Llewellyn.
Huang, S.-c. (1968). Chang Tsai's concept of *Ch'i*. *Philosophy East and West, 18*(4), 247–260.
Hume, D. (1777/1902). *Enquiries concerning the human understanding and concerning the principles of morals*, (L.A. Selby-Bigge, ed), Clarendon Press, Oxford.
Huston, P. (1995). China, chi and Chicanary: Examing traditional Chinese medicine and chi theory. *Skeptical Inquirer, 19*(5), 38–42.
Hwangbo, A. B. (1999). A new millennium and feng shui. *The Journal of Architecture, 4*(2), 191–198.

Hwangbo, A. B. (2002). An alternative tradition in architecture: Conceptions in Feng Shui and its continuous tradition. *Journal of Architectural and Planning Research, 19*(2), 110–130.

Jin, G., Fan, H., & Liu, Q. (1996). The structure of science and technology in history: On the factors delaying the development of science and technology in China in comparison with the west since the 17th century (part one). In F. Dainian & R. C. Cohen (Eds.), *Chinese studies in the history and philosophy of science and technology* (pp. 137–164). Dordrecht: Kluwer Academic Publishers.

Kaminer, W. (1999). *Sleeping with extra-terrestrials: The rise of irrationalism and the perils of piety*. New York: Pantheon Books.

Kant, I. (1787/1933). *Critique of pure reason*. (N. K. Smith, Trans.). (2nd edn). London: Macmillan, (First edition, 1781).

Kim, P. W. (2014). The wheel model of convergence STEAM education based on traditional scientific contents. *Eurasia Journal of Mathematics, Science & Technology Education, 12*(9), 2353–2371.

Knoop, A. (2001). *Feng Shui for architects*. Newsletter: American Institute of Architects. http://www.lezley.info/feng-shui.htm.

Koyré, A. (1968). *Metaphysics and measurement*. Cambridge: Harvard University Press.

Kuhn, T. S. (1970). *The structure of scientific revolutions* (2nd ed.). Chicago: Chicago University Press. (First edition, 1962).

Kwok, D. W. Y. (1965). *Scientism in Chinese thought: 1900–1950*. New Haven: Yale University Press.

Ladyman, J. (2013). Toward a demarcation of science from pseudoscience. In M. Pigluicci & M. Boudry (Eds.), *Philosophy of pseudoscience: Reconsidering the demarcation problem* (pp. 45–59). Chicago: University of Chicago Press.

Lakatos, I. (1970). Falsification and the methodology of scientific research Programmes. In I. Lakatos & A. Musgrave (Eds.), *Criticism and the growth of knowledge* (pp. 91–196). Cambridge: Cambridge University Press.

Lakatos, I. (1978). Introduction: Science and pseudoscience. In J. Worrall & G. Currie (Eds.), *The methodology of scientific research programmes: Volume I* (pp. 1–7). Cambridge: Cambridge University Press.

Laudan, L. (1983/1996). The demise of the demarcation problem. In L. Laudan *Beyond positivism and relativism: Theory, method and evidence*, Westview Press, Boulder, pp. 210–222.

Leung, K. (2010). Beliefs in Chinese culture. In *Oxford handbook of Chinese psychology* (pp. 221–240). Oxford: Oxford University Press.

Lim, J. T. Y. (2003). *Feng Shui for business and office*. Toronto: Warwick Publishing.

Lin, J. Y. (1995). The Needham puzzle: Why the industrial revolution did not originate in China. *Economic Development and Cultural Change, 43*(2), 269–292.

Lindberg, D. C., & Numbers, R. L. (Eds.). (1986). *God and nature: Historical essays on the Encounter between Christianity and science*. Berkeley: University of California Press.

Lindeman, M., & Aarnio, K. (2007). Superstitious, magical, and paranormal beliefs: An integrative model. *Journal of Research in Personality, 41*, 731–744.

Lip, E. (2008). *Feng Shui for success in business*. Singapore: Marshall Cavendish.

Mach, E. (1910/1992). Sensory elements and scientific concepts. In J. Blackmore (ed.) Ernst Mach: A deeper look, Kluwer Academic Publishers, Dordrecht, pp. 118–126.

Mahner, M. (2007). Demarcating science from pseudoscience. In T. Kuipers (Ed.), *Handbook of the philosophy of science: General philosophy of science- focal issue* (pp. 515–575). Amsterdam: Elsevier.

Mahner, M. (2012). The role of metaphysical naturalism in science. *Science & Education, 21*(10), 1437–1459.

Mahner, M. (2013). Science and pseudoscience: How to demarcate after the (alleged) demise of the demarcation problem. In M. Pigliucci & M. Boudry (Eds.), *Philosophy of pseudoscience: Reconsidering the demarcation problem* (pp. 29–59). Chicago: University of Chicago Press.

Mak, M. Y., & Ng, S. T. (2005). The art and science of Feng Shui – A study on architects' perception. *Building and Environment, 40*(3), 427–434.

Mak, M. Y., & So, A. T. (2015). *Scientific Feng Shui for the built environment: Theories and applications*. Hong Kong: City University of Hong Kong Press.
Marafa, L. M. (2003). Integrating natural and cultural heritage: The advantage of feng shui landscape resources. *International Journal of Heritage Studies 9 Part, 4*, 307–324.
March, A. L. (1968). An appreciation of Chinese geomancy. *Journal of Asian Studies, 27*(2), 253–267.
Martin, M. (1994). Pseudoscience, the paranormal, and science education. *Science & Education, 3*(4), 357–372.
Mascall, E. L. (1956). *Christian theology and natural science: Some questions in their relations*. London: Longmans Green & Co..
Matthews, M. R. (Ed.). (2009a). *Science, worldviews and education*. Dordrecht: Springer.
Matthews, M. R. (2009b). Teaching the philosophical and worldview components of science. *Science & Education, 18*(6–7), 697–728.
Matthews, M. R. (2011). From nature of science (NOS) to features of science (FOS). In M. S. Khine (Ed.), *Advances in the nature of science research: Concepts and methodologies* (pp. 1–26). Dordrecht: Springer.
Matthews, M. R. (2015). *Science teaching: The contribution of history and philosophy of science: 20th anniversary revised and enlarged edition*. New York: Routledge.
Miller, J. D. (2004). Public understanding of, and attitudes toward, scientific research: What we know and what we need to know. *Public Understanding of Science, 13*, 273–294.
Miner, E. D. (1998). *Uranus: The planet, rings and satellites*. New York: Wiley.
Moore, M. (2011). Feng shui scandals cause 20 per cent drop in business, *The Telegraph* 8th March.
National Research Council (NRC). (2013). *Next generation science standards*. Washington, DC: National Academies Press.
Needham, J. (1963). Poverties and triumphs of the Chinese scientific tradition. In A. C. Crombie (Ed.), *Scientific change: Historical studies in the intellectual, social and technical conditions for scientific discovery and technical invention, from antiquity to the present* (pp. 117–153). New York: Basic Books.
Needham, J., & Ling, W. (1956). Science and civilisation in China. In *History of scientific thought* (Vol. 2). Cambridge: Cambridge University Press.
Nickles, T. (2013). The problem of demarcation: History and future. In M. Pigliucci & M. Boudry (Eds.), *Philosophy of pseudoscience: Reconsidering the demarcation problem* (pp. 101–120). Chicago: University of Chicago Press.
Oreskes, N., & Conway, E. M. (2010). *Merchants of doubt: How a handful of scientists obscured the truth on issues from tobacco smoke to global warming*. New York: Bloomsbury Press.
Orleans, L. A. (Ed.). (1980). *Science in contemporary China*. Stanford: Stanford University Press.
Park, R. L. (2000). *Voodoo science: The road from foolishness to fraud*. Oxford: Oxford University Press.
Park, R. L. (2008). *Superstition: Belief in the age of science*. Princeton: Princeton University Press.
Paton, M. J. (2007). Feng shui: A continuation of the Art of Swindlers? *Journal of Chinese Philosophy, 34*(3), 427–445.
Perry-Hobson, J. S. (1994). Feng Shui: Its impacts on the Asian hospitality industry. *International Journal of Contemporary Hospitality Management, 6*(6), 21–26.
Pigliucci, M. (2013). The demarcation problem: A (Belated) response to Laudan. In M. Pigliucci & M. Boudry (Eds.), *Philosophy of pseudoscience: Reconsidering the demarcation problem* (pp. 9–28). Chicago: University of Chicago Press.
Pigliucci, M., & Boudry, M. (Eds.). (2013). *Philosophy of pseudoscience: Reconsidering the demarcation problem*. Chicago: University of Chicago Press.
Popper, K. R. (1963). *Conjectures and refutations: The growth of scientific knowledge*. London: Routledge & Kegan Paul.
Porkert, M. (1982). The difficult task of blending Chinese and Western science: The case of the modern interpretations of traditional Chinese medicine. In G. Li, M. Zhang, & T. Cao (Eds.),

Explorations in the history of science and technology in China (pp. 553–572). Shanghai: Shanghai Chinese Classics Publishing House.
Preece, P. F. W., & Baxter, J. H. (2000). Scepticism and gullibility: The superstitious and pseudoscientific beliefs of secondary school students. *International Journal of Science Education, 22*(11), 1147–1156.
Queenan, J. (2002). Beyond Feng Shui. *Skeptical Inquirer, 12*(4).
Radder, H. (Ed.). (2003). *The philosophy of scientific experimentation*. Pittsburgh: University of Pittsburgh Press.
Randi, J. (1987). *The faith healers*. Buffalo: Prometheus Books.
Randi, J. (1995). *An encyclopedia of claims, frauds, and hoaxes of the occult and supernatural*. New York: St. Martin's Press.
Ricci, M.: 1617/1953 On the Christian mission among the Chinese. In L.L. Gallagher, China in the sixteenth century: The Journals of Matthew Ricci, 1583–1610, Random House, New York.
Rossbach, S. (1983). *Feng Shui: The Chinese Art of Placement*. New York: E.P. Dutton.
Rossbach, S. (1987). Interior design with Feng Shui. New York: E.P. Dutton.
Rule, P. A. (1986). *K'ung-tzu or Confucius? The Jesuit interpretation of Confucianism*. Sydney: Allen & Unwin.
Rutt, R. (1996). *The book of Changes (Zhouyi): A bronze age document*. Richmond: Curzon Press.
Sagan, C. (1996). *The demon-haunted world: Science as a candle in the dark*. London: Headline Book Publishing.
Schofield, R. E. (1970). *Mechanism and materialism: British natural philosophy in an age of reason*. Princeton: Princeton University Press.
Shapiro, J. (2001). *Mao's war against nature: Politics and environment in revolutionary China*. Cambridge: Cambridge University Press.
Shermer, M. (1997). *Why people believe weird things: Pseudoscience, superstition, and other confusions of our time*. New York: W.H. Freemand & Co..
Shermer, M. (2002). *'Feng Shui', The Skeptics encyclopedia of pseudoscience* (Vol. 2, pp. 111–112). Santa Barbara: ABC-CLIO.
Sivin, N. (1984). Why the scientific revolution did not take place in China – Or Didn't it? In E. Mendelshohn (Ed.), *Transformation and tradition in the sciences* (pp. 531–554). Cambridge: Cambridge University Press.
Skinner, S. (1980). *Terrestrial astrology: Divination by geomancy*. London: Routeledge & Kegan Paul.
Skinner, S. (2008). *Guide to the Feng Shui compass: A compendium of classical Feng Shui*. Singapore: Golden Hoard Press.
Skinner, S. (2015). *Advanced flying star Feng Shui*. Singapore: Golden Hoard Press.
Smith, R. J. (1991). *Fortune-tellers and philosophers. Divination in Chinese society*. Boulder: Westview Press.
Spence, J. D. (1984). *The memory palace of Matteo Ricci*. New York: Penguin.
Tang, Y. (2015a). *Confucianism, Buddhism, Daoism, Christianity and Chinese culture*. Dordrecht: Springer.
Tang, Y. (2015b). Some reflections on new confucianism in Chinese mainland culture of the 1990s. In Y. Tang (Ed.), *Confucianism, Buddhism, Daoism, Christianity and Chinese culture* (pp. 67–78). Dordrecht: Springer.
Tang, Y. (2015c). On the clash and coexistence of human civilizations. In Y. Tang (Ed.), *Confucianism, Buddhism, Daoism, Christianity and Chinese culture* (pp. 291–307). Dordrecht: Springer.
Thurs, D. P., & Numbers, R. L. (2013). Science, pseudoscience, and science falsely so-called. In M. Pigliucci & M. Boudry (Eds.), *Philosophy of pseudoscience: Reconsidering the demarcation problem* (pp. 121–144). Oxford: Oxford University Press.
Tobin, K. (2000). Constructivism in science education: Moving on. In D. C. Phillips (Ed.), *Constructivism in education* (pp. 227–253). Chicago: National Society for the Study of Education.

Tobin, K. (2015). Connecting science education to a world in crisis. *Asia-Pacific Science Education, 1*, 2. doi:10.1186/s41029-015-0003-z.

Too, L. (1998). *Essential Feng Shui: A step-by step guide to enhancing your relationships,health and prosperity*. London: Random House.

Turgut, H. (2011). The context of demarcation in nature of science teaching: The case of astrology. *Science & Education, 20*(5–6), 491–515.

Wegman, M. E. (1980). Biomedical research: Clinical and public health Aspects. In L. A. Orleans (Ed.), *Science in contemporary China* (pp. 269–294). Stanford: Stanford University Press.

Weinert, F. (1995). The Duhem-Quine thesis revisited. *International Studies in Philosophy of Science, 9*(2), 147–156.

Wong, G. (1963). China's opposition to Western science during the late Ming and Early Ch'ing. *Isis, 54*(1), 29–49.

Wright, J. (2010). *Mission to China: Matteo Ricci and the Jesuit Encounter with the east*. London: Faber.

Yoon, H.-K. (2006). *The culture of Fengshui in Korea: An exploration of East Asian Geomancy*. Plymouth: Rowan & Littlefield.

Yosida, M. (1973). The Chinese concept of nature. In S. Nakayama & N. Sivin (Eds.), *Chinese science: Explorations of an ancient tradition* (pp. 71–89). Cambridge, MA: Harvard University Press.

Zhang, D. (2002). *Key concepts in Chinese philosophy*, (translated and edited by Edmund Ryden). Beijing: Foreign Languages Press.

Chapter 2
The Enlightenment: Truths Behind a Misleading Abstraction

Robert Nola

In trying to come to understand what ‘The Enlightenment’ means, enlightenment is not always readily forthcoming. Historians are prone to “periodize” history (mainly European history) using terms such as ‘The Renaissance’, ‘The Reformation’, ‘The Age of Reason’, ‘The Enlightenment’ (are these last two the same?), ‘The Romantic Age’, ‘The Age of Revolutions’, ‘The Modern Age’, and so on. What distinguishes one period from another is often hard to determine. Here the focus is on the period of “The Enlightenment”, its scope, the content of its characteristic doctrines, their epistemic standing and some critics of the (idea of) the Enlightenment.

Of the multifarious issues that surround The Enlightenment, the following few are selected for attention in this essay. Section 2.1 of this paper canvases a few of the competing accounts of when The Enlightenment occurred, how many “enlightenments” there were and what some of its central doctrines might be. As a leading hypothesis I draw (but not uncritically) on Jonathan Israel’s idea that there are just two aspects to The Enlightenment, the Radical and the Moderate, and his more detailed account, in the form of eight cardinal points, of how one might characterise the Radical Enlightenment. Section 2.2 makes some suggestions that expand on the role of science in The Enlightenment that are not well captured in Israel’s account. Section 2.3 develops some brief comments about what it might be for a person to be enlightened about some subject matter. Note here that the word ‘enlightened’ is an adjective that is applied to a person. This is to be distinguished from its nominalization when it is turned into the abstract noun ‘The Enlightenment’. It will be claimed that its denotation remains quite unclear; if not treated with care it is a misleading abstraction.

In Sect. 2.4 it is suggested that talk about ‘The Enlightenment’ is better replaced by an epidemiological approach that considers the scatter of enlightened and unenlightened people at a time in any given society. This is the kernel of hard fact about

R. Nola (✉)
School of Humanities, The University of Auckland, Auckland, New Zealand
e-mail: r.nola@auckland.ac.nz

M.R. Matthews (ed.), *History, Philosophy and Science Teaching*, Science: Philosophy, History and Education, DOI 10.1007/978-3-319-62616-1_2

"The Enlightenment" as it exists in a given society at a time. The approach taken here is that of methodological individualism in which a seemingly holistic concept like "Enlightenment" is given an analysis in terms of individual people who are enlightened to some degree or in some respect. Section 2.5 considers some of the definitional comments made by Mendelssohn and Kant in their respective accounts of The Enlightenment; these are just two of the many early attempts to characterise the Enlightenment. The final Sects. 2.6 and 2.7 consider some of the claims made by some recent detractors of the Enlightenment (such as John Gray, Horkheimer and Adorno). Their claims have gained some currency but, as will be argued, they are not convincing and are often implausible. But they are part of the current widespread denigration of "The Enlightenment" that has reached beyond philosophy and sociology into science education where typically one author, for example, maintains that: 'Enlightenment epistemology of science is imbued with cultural meanings of gender' and that the Enlightenment gave rise to all manner of undesirable dualisms (Brickhouse 2001, p. 283).

2.1 What Is Enlightenment?

There is little agreement as to when "The Enlightenment" started. Many suppose that it began at some time during the first half of the 1700s though others push its origin back to a time in the 1600s in order to include the works of Descartes (1596–1650), Spinoza (1632–1677) and Newton (the first edition of his *Principia Mathematica* was published in 1687) as crucial to philosophical and scientific aspects of "The Enlightenment". It remains a moot point as to whether what some call "the scientific revolution" is to be included within The Enlightenment. The scientific revolution was inaugurated much earlier by Copernicus (his *De Revolutionibus* was published just before his death in 1543) and was continued by Bacon, Galileo, Kepler, who were followed by many others.

If "the scientific revolution" is regarded as an independent matter (as it is here), it remains important to trace the influence of both science and the methods of science on "The Enlightenment" conception of rationalism and reason. Matthews follows many in saying: 'The eighteenth-century Enlightenment was the fruit of the seventeenth-century scientific revolution' (Matthews 2015, p. 23). Many suppose that "The Enlightenment" ended by the end of the eighteenth century; the decade of the French Revolution 1789–1799 is commonly said to mark its end.

For some, for example Habermas, these dates are too restrictive. There is still supposed to be an ongoing "project of enlightenment"[1] which remains unfinished.

[1] There is a quite ordinary sense of the phrase 'The Enlightenment Project' in which we can say that some of the ideas and ideals that were inaugurated in the 17th and 18th The Enlightenment period are yet to be fully articulated or even adequately implemented (such as sexual equality). Harbermas, of course, might well invest the phrase with a different meaning as when he talks of "Modernity – an Unfinished Project" at the beginning of the 'Preface' to Habermas 1990, p. xix. See also the collection by Honneth and others 1992.

More broadly, Bertrand Russell held the view that the enlightenment was a phase in a more general progressive development which began in antiquity, and that reason and challenges to the established order were constant ideals from that time until now. Given what we ordinarily understand by being enlightened and using reason, Russell is right in that it would be odd to claim that the Ancient Greeks, some of the medieval philosophers, as well as theoreticians in our own time, were not enlightened. A similar point is acknowledged by a leading historian of The Enlightenment, Peter Gay, who speaks of a 'first enlightenment' to be found in Ancient Greece and the Roman Empire.[2] For him the subsequent "second" seventeenth–eighteenth century enlightenment period is said to be "pagan" in that it rejects much of the intervening Christian view of the world.

Is the "The Enlightenment" the same sort of thing in different places in Europe? Some point to the distinctive character of national enlightenments such as "The Scottish Enlightenment", "The French Enlightenment", and so on. The historian John G. A. Pocock in his *Barbarism and Religion,* Vol. 1, *The Enlightenments of Edward Gibbon* deliberately uses the plural 'Enlightenments' in the subtitle of his book about the various, distinct enlightenments with which Edward Gibbon was allegedly involved. He underlines this plurality by saying: "it is a premise of this book that we can no longer write satisfactorily of 'The Enlightenment' as a unified and universal intellectual movement"(Pocock 1999, p. 13). So we are to drop the 'The' indicating uniqueness. More broadly this suggests that in the attempt to say what "The Enlightenment" is, we are to abandon the idea that in any definition of the concept there is to be found a common core of characteristics which the allegedly various instances of the several "Enlightenments" all share. To use an idea of Wittgenstein, there might still be a family resemblance between the various kinds of Enlightenment even though there is no essential common core to them all. However on this view it does not emerge clearly just how many distinct "Enlightenments" there really are.

In three volumes, each about 900 pages long, another prominent historian of The Enlightenment, Jonathan Israel, resists Pocock's position and claims that there were just two Enlightenments in Europe and America - Radical and Moderate mainstream (or conservative).[3] Leading radical enlighteners were, for example, Spinoza, Bayle, Meslier, d'Alembert and Diderot; they advanced social and political ideas that were radically opposed to prevailing restrictive views advocated by the church and absolutist monarchies. Leading moderate enlighteners included, for example, Hume, Locke, Voltaire and (the later) Rousseau.[4] To various extents they drew back

[2] Gay 1967, volume 1; see Book One, Chapter Two, entitled 'The First Enlightenment' and the bibliographical essay on pages 464–81. Note that the subtitle to volume 1 is 'The Rise of Modern Paganism'.

[3] In Israel 2006, chapters 1.1 and 34 'Postscript' the case is made against the "many" enlightenments of Pocock and a supposed "one" enlightenment suggested by Gay. He makes a case for there being just two trends in the enlightenment period, radical and moderate. Though disputed, this will be provisionally accepted here since it is not germane to my main purpose in mentioning Israel's work.

[4] For an elaboration of this distinction see Israel 2006, section 1.1, pp. 3–15 and section 34 'Postscript'. The later Rousseau is even said to become '… the moral "prophet" as it were of one form of Counter-Enlightenment' (*ibid*., p 11).

from the more radical stance and even in some cases were apologetic towards, if not supportive of, the absolutist tendencies to be found in churches, governments and/or monarchies. Of the two kinds of enlightenment the moderate became the much more dominant in its public support and approval.

Unlike many historians of The Enlightenment, Israel assists discussion of what doctrines the Radical Enlightenment endorsed by distilling out eight, brief cardinal points which he takes to characterise it. In this essay I will, with one modification, provisionally accept Israel's cardinal points as a useful hypothesis to keep in mind; though it should also be recognised that the thinkers of the Enlightenment were quite diverse in their doctrines and not all would have endorsed every one of the following cardinal points in exactly the form expressed[5]:

(1) adoption of philosophical (mathematical-historical) reason as the only and exclusive criterion of what is true;
(2) rejection of all supernatural agency, magic, disembodies spirits and divine providence;
(3) equality of all mankind (racial and sexual);
(4) secular 'universalism' in ethics anchored in equality and chiefly stressing equity, justice and charity;
(5) comprehensive toleration and freedom of thought based on independent critical thinking;
(6) personal liberty of life style and sexual conduct between consenting adults, safeguarding the dignity and freedom of the unmarried and homosexuals;
(7) freedom of expression, political criticism, and the press, in the public sphere;
(8) democratic republicanism as the most legitimate form of politics.[6] (Israel 2006, p. 866)

[5] Abner Shimony makes a good point about the diversity of views of leading members of the Enlightenment. They were: 'rationalists, empiricists and mediators; Newtonians and dissenters from Newton: system builders and skeptics; theists, deists, agnostics and atheists; cultural universalists and cultural pluralists; advocates of a variety of bases of ethics; a wide spectrum of political theorists; physicalists and mentalists; determinists and advocates of free will; trusters and distrusters in benevolent despotism; believers and disbelievers in the inevitability of human progress. Some core commitments, shared by almost all of the Enlightenment philosophers, can be reasonably extracted and these, in my opinion, need little modification to be permanently valuable' (Shimony 1997, p. S2). Shimony then proceeds to give a list of 10 core commitments of The Enlightenment which differ from those of Israel; but there is no deep inconsistency, or great distance, between the two lists. Shimony's list puts greater emphasis on matters to do with science and could have just as well been used here instead of Israel's eight cardinal points. Finally Shimony examines four criticisms of The Enlightenment and makes convincing responses to them (pp. S3-S9). His account is laid out and discussed in Matthews (2015, pp.24–26).

[6] In Israel 2011, section 1.1 ('Defining the Enlightenment', pp. 1–8) the author reviews other attempts at a definition of 'The Enlightenment' and proposes something like (1) to (8) in truncated form. He takes it to be a unitary movement occurring on both sides of the Atlantic from about 1680 to 1800 which is driven by philosophy (here Spinoza is said to have had an important role at the beginning) and is socially ameliorative in transforming accepted values and practices. The extent to which the Enlightenment is linked to revolution is one aspect of the division between Radical

We can take these eight to points embody central beliefs and values of enlightenment thought. They can be divided into two broad categories, scientific ((1) and (2)) and social-ethical ((3) to (8)).[7] It is important to note that there is no logical link between scientific aspects of the enlightenment and its social/ethical aspects; each is logically independent of the other. But it just so happens that they do accompany one another, largely because of the more general background role of reason supposed in The Enlightenment that draws upon the scientific revolution.

The first two points are an attempt to characterise philosophical and scientific aspects of the Enlightenment; but (1) does not do it adequately as will be argued in Sect. 2.2. Clearly (2) distances science from religion. However this Enlightenment goal has not been realised fully; it is still a matter of dispute when one considers the resurgence of religious views which oppose science such as creationism or intelligent design or the moderate doctrine of NOMA championed by Stephen J. Gould which gives science and religion non-overlapping, consistent and complementary domains of concern.[8] In contrast (3) to (8) spell out social and ethical aspects of Israel's Radical Enlightenment. Moderate Enlightenment departed from Radical Enlightenment in that it compromised on some of these social-ethical principles; for some of the non-radicals there was even a backsliding into supporting forms of absolute monarchy, authoritarianism (political and religious), and the like.

These eight cardinal points do not now have the same radical edge that they might have had in the eighteenth century. But there is a good sense in which we can agree with Habermas, Russell and Gay that the Enlightenment project is unfinished. In some respects the philosophical clarification of what each entails has yet to be fully articulated and agreed upon; and some of the ethical and political goals are only now being realised in some countries (e.g., the rights of gays, same sex marriage, sexual equality, the exercise of tolerance, and the like). Depending on what country one is in, the conflict between religion and science embodied in (2) still looms large. And the same can be said for the characterisation of science in the seventeenth–eighteenth century enlightenment period. Twentieth century philosophy of science deepens our understanding of both science and philosophy well beyond what might have been envisaged in that period; and this is still an ongoing process.

---

and Moderate trends within the Enlightenment. Cassirer has a different view from Shimony and Israel: 'The true nature of Enlightenment thinking cannot be seen in its purest and clearest form where it is formulated into particular doctrines, axioms, and theorems; but rather where it is in process, where it is doubting and seeking, tearing down and building up' (Cassirer 1951, p. ix). But there need be no inconsistency between picking out some cardinal points and also understanding the activity of thinking as some kind of process.

[7] Bristow, 2010, distinguishes three *different areas of enlightenment: scientific; moral/political; aesthetic. Gay,* 1970*, chapters 5 and 6 also includes aesthetics in the various areas of enlightenment, as does Cassirer,* 1951*, chapter VII.*

[8] For an account of his NOMA, see Gould 1999. For one of the many recent accounts of the conflict between religion and science which rejects Gould's distinction, see Coyne 2015, pp. 106–12.

Given the different ways in which the phrase ‘The Enlightenment’ could be used, some writers might well have thought that the best thing to do is to drop it altogether. But dropping it has the drawback that a number of eighteenth century thinkers used a term equivalent to the English word ‘Enlightenment’ to refer to their period of activity. The term ‘The Enlightenment’ appears to be of late usage in English; according to the on-line OED, the use of the expression beginning with ‘The’ followed by capital ‘E’ was only common in the nineteenth century after the time when some say “The Enlightenment” period had ended. On the continent their various terms for ‘The Enlightenment’[9] had a longer history and towards the end of the eighteenth century writers on the topic became more self-reflective about what “The Enlightenment” was supposed to be.

This self-reflection began when Johann Zöllner posed an innocent question ‘What is Enlightenment?’ in a footnote of a paper he published in the December 1783 issue of *Berlinische Monatsschrift*. The reflection began in earnest when the same journal published the next year a series of articles which attempted to answer Zöllner’s question, beginning with those of Moses Mendelssohn and Immanuel Kant (these are discussed in Sect. 2.5).[10] But there was no general agreement as to what The Enlightenment was. So little clarity about the nature of it was achieved that an anonymous 1790 article in the Deutsche Monatsschrift ‘… argued that the term had become so divorced from any clear conventions of usage that discussions of it had degenerated into “a war of all against all” between combatants who marshalled their own idiosyncratic definitions’ (Schmidt 1996, p. 2).

Though the eight cardinal points listed by Israel help anchor discussions about the beliefs and values of enlightenment thought, some might contend that we still remain in the same late eighteenth century state of conflict concerning its definition. Given what some contemporary critics of the Enlightenment think it is (see Sects. 2.6 and 2.7), one has good grounds for saying that the situation has not changed very much today. The remainder of this essay attempts to say to what extent it is possible to characterise “The Enlightenment” and to dispel some current misconceptions about it.

2.2 Science and The Enlightenment

Historians do not always have sufficient understanding of doctrines within philosophy and the philosophy of science; Israel’s philosophical cardinal point (1) is a good example of this. But the problems here can be readily repaired by making some broad comments about the development of science and the methods of science from the sixteenth to the eighteenth centuries that can replace what is said in Israel’s first

[9] A related term in German is *Aufklärung* and in French is *éclaircissement*. All three terms connote the casting of *light* upon some matter, or a process of bring something to light.

[10] These two papers and three other contemporary papers are collected in Part I of Schmidt (ed.) 1996.

cardinal point (1) (but perhaps not as succinctly). Here Israel lists one of the ways in which science and its philosophy has influenced some of the doctrines of The Enlightenment: he speaks of 'philosophical (mathematical-historical) reason as the only and exclusive criterion of what is true'. But reason is reason, whether in the context of philosophy, mathematics or history. And in none of these cases is it a criterion for truth; this is a separate matter (which reason might well presuppose). The important matter that can be readily agreed upon is the broad role of scientific reasoning in "The Enlightenment" (setting aside the irrelevant appeal to mathematics and history). But what might this be?

Let us set aside questions about whether what is commonly called the "Scientific Revolution" was in one sweep quite revolutionary. However, the models of the cosmos provided by Copernicus in his 1543 *De Revolutionibus* inaugurated a chain of rethinking of theories of dynamics and cosmology that were developed by a number of thinkers from Galileo to Newton. Though much of this occurred well before several dates suggested for the start of The Enlightenment period, it had an important influence as a scientific exemplar of the kind of reason that any Enlightenment thinker thought they should try to emulate.

In considering this, we need to distinguish between the *products* of the various kinds of scientific thinking, such as the laws, theories, postulates and models that were developed, and the *processes* that were employed to arrive at these products. These processes fall under the general notion of the methods of science such as methods for discovering laws and theories, methods for assessing rival theories (such as Newton's versus Descartes' theories of motion in a resisting medium in which Newton's theory was triumphant), methods for constructing idealized models of real systems (first developed by Galileo but subsequently followed by others), and the like. Not only were the products of the "scientific revolution" quite novel within The Enlightenment period; but also the methods of science themselves were novel and contributed to our idea of how reason can function when dealing with not only the natural world but also the human and social worlds to which Enlightenment thinkers were to turn their attention. It is this broad appeal to the notion of the role of reason and method in science and elsewhere that can replace Israel's cardinal point (1).

But a little more needs to be said of this. The works of scientists from Copernicus onwards often contain an account of what the role of reason ought to be in science. Francis Bacon promulgated principles of reason such as principles of induction and inductive elimination. Descartes was preoccupied by setting out his 'Rules for the Direction of the Mind'. Much more successful and influential in science were Newton's 'Rules of Reasoning in Philosophy' that stand at the beginning of Book Three 'System of the World' in his *Principia* and which were employed in arriving at his law of Universal Gravitation. Subsequently philosophers developed theories about the extent and limitations of reason which are still open to debate (for example, Kant in his 1781 *Critique of Pure Reason*). If there is an unfinished project of "The Enlightenment" it is in the area of the philosophy of science and its articulation of what scientific reason might be, and reason more generally. Theories of method, logic and the nature of rationality grew in the twentieth century leading to a deepening account of scientific reason along with more broad theories within epistemology.[11] The eighteenth century Enlightenment had only an intimation of this.

Some of the issues involved here are well-stated by Rebecca Goldstein in her recent critical review of a book on The Enlightenment:

> … the soul of the Enlightenment unmistakably lay in an endorsement of reason, though not necessarily *a priori* reason, since many Enlightenment thinkers were robust empiricists …. They appealed to rational powers, which meant that only certain kinds of justification for beliefs would be countenanced—namely those that were, in principle, accessible to all humans relying only on our shared cognitive capacities. Insisting on this standard was the Enlightenment's revolution. There could be no privileged knowers who appealed to special sources of knowledge—available to them by way of heavenly revelation, or authoritative status, or intimations to which their group was privy. Even tradition couldn't stand merely on its longevity but had to justify its right to continue to exist.
>
> The Enlightenment, in short, amounted to an assertion of epistemic democracy. Whatever can be known by one person can, in principle, be known by all, as long as they master the techniques for knowing that are relevant to a field. It's no accident that the development of modern empirical science was intertwined with the Enlightenment. (Goldstein 2015, p. 51)

Talk of there being no privileged knowers with a special inside track to knowledge and there being epistemic democracy for all of those who are willing to make the intellectual effort, not only underpins Israel's point (2) about the rejection of the supernatural but prepares the ground for the positive features of method and reason suggested in point (1) that give content to the principles of an epistemic democracy advocated by many enlightenment thinkers. It is this conception of epistemic democracy, along with the principles of scientific reason, that were being developed from the eighteenth century onwards, which lie behind Israel's cardinal points (1) and (2). It is this expanded conception of these points which will be assumed here.

2.3 What Is It to Be Enlightened?

What do we normally mean by being enlightened? In our ordinary use of the term a person can be enlightened when they are instructed about, or informed about, or have some "“light” cast upon", some matter about which they previously knew little or nothing. Negative connotations are added when it is said that a person is at the same time freed from ignorance, superstition or prejudice. In addition, a person can be said to be enlightened when they acquire some understanding of some matter or be in a position to offer an explanation of it. Thus in reading Newton's Principia one can become enlightened, say, about the universal character of gravitational

[11] There is a good account of aspects this in Shimony 1997. Shimony is a philosopher of science who is well known for defending Bayesianism as the method of science to adopt; he is not an historian like most of the writers considered so far. There are also a few hints about the role of science and it methods in Cassirer 1951, chapter II, though his comments are largely with respect to Newton and some of Newton's contemporaries.

attraction and how the law that governs it works. Negative connotations are emphasised when it is added that one is freed from some former prejudice, superstition or ignorance about the nature of gravitation as it acts in the universe.

Could one say that one's tax consultant enlightens one about one's tax returns? This is not ruled out in the above and remains an acceptable use of the term in ordinary English when one is informed about factual matters. (However note that no negative connotation such as superstition or prejudice need be involved; it is simply a matter of not knowing.) If one wished to set aside such a case, one would have to add that being informed about factual matters may not be the proper intensional object of "being enlightened about …". Rather, the proper object of being enlightened is acquiring some explanatory knowledge or understanding rather than merely knowledge of particular fact. Enlightenment about, say, gravitational attraction is akin to gaining knowledge of, or understanding about, Newton's theory of gravitational attraction and its associated law[12]; this is different from merely getting knowledge of a factual matter such as the gravitational mass of the Moon. In addition becoming enlightened may well involve using some of the principles of epistemic democracy suggested in the previous section.

Setting aside what some early writers may have said about the nature of the enlightenment (see Sect. 2.5) we may proceed in a slightly anachronistic way and consult the on-line OED. It says two things about being enlightened: (1) '… bringing someone to a state of greater knowledge, understanding, or insight; the state of being enlightened in this way'. Here there is emphasis on the state of acquiring some initial knowledge or understanding. But further emphasis on the word 'greater' suggests a pervasive feature of past and present science, viz., its ability to grow. Science is not static in what it produces; in line with its epistemic democracy, it is dynamic and revisionary giving us new or improved laws, hypotheses and theories as well as methods and techniques of observation gathering and experimentation.

Within theories of scientific method criteria have been proposed in which we can determine the extent to which we have improved knowledge (or more correctly, beliefs) over previous knowledge (beliefs); or improved understandings or explanations when compared with previous attempts at understanding or explanation; or we have ways of determining any increase in truth-likeness or verisimilitude; or we have ways of determining when we have some degree of evidential support, or greater evidential support, for our laws, theories and hypotheses. Here emphasis is placed on the idea of enlightenment being a process within the growth of knowledge. There is nothing novel about this aspect of enlightenment so defined. It is a feature of science both before and after the commonly suggested seventeenth and eighteenth century scope of The Enlightenment period.

[12] Of course one might not be fully enlightened about Newton's theory of gravitational attraction but only partially so. However partial enlightenment is a step along the path to greater enlightenment as one's knowledge and understanding develops. Think of the more limited understanding of Newton himself and his application of his theory when compared with later developments of the theory of gravitation suggested by Laplace, Lagrange and Hamilton.

The on-line OED goes on to make an important contrast between an earlier state of pre-enlightenment understanding which is then replaced by an enlightened view: (2) 'The action or process of freeing human understanding from the accepted and customary beliefs sanctioned by traditional, esp. religious, authority, chiefly by rational and scientific inquiry into all aspects of human life, which became a characteristic goal of philosophical writing in the late seventeenth and eighteenth centuries.' This is not merely a matter of getting greater and greater understanding, this being one of the important critical functions of science in relation to earlier sciences. Importantly enlightenment has a further critical and revisionary function in that customary, traditional and religious beliefs and various kinds of authorized beliefs are to be replaced, this being the first step on the path to initial (if not complete) enlightenment. And by what means are the pre-enlightened beliefs and values to be replaced by enlightened beliefs and values? This is something called "rationality" or "scientific method" - whatever they are.[13] Thus the methods of science help us in both aspects of the notion of enlightenment distinguished by the OED. Its use helps people make the first move from pre-enlightened beliefs and values to enlightened beliefs and values; and then it helps people to get improved beliefs once the initial move has been made out of the pre-enlightened phase.

The above will suffice to say what the property of being enlightened might be when predicated of persons. In addition the kind of knowledge involved is given some content by the eight cardinal points listed by Israel (noting the revised (1)). Thus a person is enlightened when they apply scientific methods and advocate toleration, freedom of expression, sexual equality, republicanism, etc. To require that they also conduct their lives in the light of these principles and actually practice what they advocate is to adopt a strongly committed version of enlightenment. They are also enlightened when they use some principles of scientific method to argue for some point of view and do not abandon epistemic democracy in favour of some kind of epistemic privilege, as might their religious rivals.

What now counts as being unenlightened? A necessary condition for a person to be enlightened would be, for example, to believe in toleration, or freedom of expression or sexual equality (i.e., to advocate most or all of the eight cardinal beliefs and values listed by Israel); to fail to so believe would make one unenlightened. However mere belief might not be enough for enlightenment: one is required also to practice what one believes leading to a more strenuous form of enlightenment. Note that not being enlightened is not to be confused with the Counter-Enlightenment; this is a philosophical and political movement opposed to some or all of the main tenets of The Enlightenment (such as Israel's eight points). One can be unenlightened but not be a member of the Counter-Enlightenment.

[13] As already suggested, the nature and scope of scientific method and rationality, though an important part of the seventeenth and eighteenth century enlightenment period, is still part of the unfinished project of the enlightenment. See for example the growth of statistical methods or random clinical trials during twentieth century science. There are still issues to be addressed in a full account of the nature of scientific method and the scope of rationality in various spheres. This is suggested in the revisionary comments on Jonathan Israel's cardinal points (1) and (2) of the previous section 2. See also Shimony 1997.

2.4 The Enlightenment Versus the Epidemiology of Being Enlightened

Epidemiology is the study of the distribution of some property throughout a given population (which could be human or non-human, though here we will stay with human populations). One could focus on any property (over a given time). Typically within epidemiology the property is a medical one, such as the spread of influenza in a population over a given time. But one can consider the distribution of non-medical properties across a population such as being over 2 m tall, or owning two or more homes or having more than 10 million dollars in wealth. The population is then divided into two groups (which can have fuzzy boundaries); those who have the specified property and the complementary group of those who do not have the property.

In the same way one can also consider the distribution of mental properties over a population, such as the property of believing in some proposition, that p. Thus in a given population some will believe that the free market is the most efficacious form of economic organisation while others will not; some will believe that God exists while others will not; some will believe in creationism while others will not; and so on for any belief whatever. Here the population is divided into two groups: those who believe some claim that p and the complementary group who do not believe that p (which can be further divided into those who positively disbelieve that p, or have no belief either way that p, or have suspended belief in p, or are so confused that they do not know what they believe).[14]

Now apply the epidemiology of beliefs to the particular case of the beliefs characteristic of "The Enlightenment" (such as the conjunction of (most of) Israel's eight cardinal points). It would be an empirical matter to determine just how widespread were these Enlightenment beliefs at any given time in, say, the seventeenth and eighteenth centuries across Europe (though not an empirical investigation that one could easily carry out now).

Israel gives us a hint of these empirical matters when he says:

> In this present work, over seventy writers French, Dutch, German, Italian and British active within the period between 1660 and 1750 have been identified as significantly contributing to formulating and publicizing the ideas which drove the Radical Enlightenment, in conjunction with social forces and grievances where these helped to produce the ideas and shape the controversies. … among the five main 'national' contingents, the French group turns out to have been by far the largest, the Dutch the second largest, and the British group seemingly the smallest.' (Israel 2006, p. 867)

We can say that, in a given society, a few people (such as the above writers) are the enlightened at that time, and indeed the radically enlightened. Just how many fellow travellers in each society were also radically enlightened is hard to tell. But we can say that the number of people in a given society who were (radically) enlightened

[14] On the application of epidemiology to cultural contexts see Sperber 1996, 'Introduction' pp. 1–6 and Chapter 4 'The Epidemiology of Beliefs'.

was quite small when compared with the number of people in the complementary class who were not enlightened at all (and this would include a small number of members of the Counter-Enlightenment who knew of the doctrines of the radically enlightened few but were opposed to them).

This highlights the way in which the use of the phrase ‘The Enlightenment’ can mislead. It is an abstract noun which is not clear in its denotation. Does it refer to a period of time? Or a body of doctrine? Or some people? Or a movement or a process? Or what? Context of use might not always help here. However an approach based on the epidemiology of belief invites us to consider (i) the adjective ‘enlightened’ which can apply to the members of a class of people and (ii) the adjective ‘unenlightened’ which applies to the members of a complementary class. A period, or an “Age”, might be characterised by having a small number of enlightened people in it while also containing a large number of unenlightened people. In such a case the phrase “The Enlightenment” when applied to the Age as a whole will be misleading in another way.[15]

Here there is an important distinction to mark that perhaps Kant is trying to make when he says: ‘If it is asked “Do we now live in an *enlightened* age?” the answer is “No”, but we do live in an age of *enlightenment*” (Kant 1996, p. 62). We do not live in an enlightened age because of the paucity of people who are in fact enlightened; the complementary class of the unenlightened is, in comparison, quite large and they are dominant. But because there are some enlightened people, as few as they may be, there is some enlightenment in the age.

Importantly there is no overall thing such as “The Enlightenment” to talk about. In one of its uses the phrase ‘The Enlightenment’ might be thought to pick out an enlightened age; but according to Kant there is no such thing to pick out as there is no general enlightenment distributed across all, or most, people. In another of its uses the phrase ‘The Enlightenment’ might refer to an “age of enlightenment”; but then few in the age are enlightened and there is a much bigger complementary class of people to take into account who are not enlightened. What is being talked about is often unclear or misleading. The distinction Kant attempts to make becomes clearer on the epidemiological approach taken here. It separates the use of an adjective ‘enlightened’ when applied to people (or not as the case may be) from the more obscure ‘The Enlightenment’ which is unclear in its denotation and so can mislead those who use the term.

Since being enlightened is not an “all-or-nothing” matter, the epidemiological approach needs modification. Suppose we have some persons x who live in a given society S (or Age) over a time t; and suppose further that they hold some enlightened beliefs and values, B, on some subject matter M. The beliefs they hold might be some of the eight given in Israel’s (modified) list, or at least some smaller number of them which form a cluster. The first modification arises as follows. We should not expect that person x always be fully enlightened about subject matter M; they may

[15] Approaching matters in this way gives an account of the seemingly holist notion of Enlightenment in terms of the mental properties of people; in this way the proposed analysis is of a piece with the doctrine of methodological individualism.

be only partially so (as an example see footnote 12 on this). Taking this into account allows that a person's enlightenment can come in degrees which can then be comparative.

As an illustration consider John Locke's well known account of tolerance. Locke's attempt to develop an account of the concept of toleration is at best partial; modern accounts are, in several respects, an improvement. Infamously Locke restricts the extension of the concept of those to be tolerated; his account is partial since atheists are not to be included and he has serious doubts about Catholics. (Locke 1689/2010–15, section 10, p. 21). Since Locke's time we have expanded the extension of those who must be tolerated making it a universal ideal. However the extent to which tolerance is actually practised between groups and nations is a separate empirical socio-historical matter which tells us about the degree to which enlightenment ideals are actually realised. For various groups of people the extension of tolerance is at best partial; so we can legitimately speak of the unfinished project of enlightenment.

A second illustration is the case of David Hume who is often cited as a leading enlightenment figure. Is he always enlightened when it comes to race? Hume tells us that 'the most rude and barbarous of the whites, such as the ancient Germans, the present Tartars, have still something eminent about them" (Hume 1985, p. 208, fn. 10). But not so the "negroes" as Hume calls them. None of them have any redeeming features at all: 'I am apt to suspect the negroes to be naturally inferior to whites". That negroes accomplish anything is to be compared to '… a parrot who speaks a few words plainly' (loc. Cit.). Hume's espousal of an appalling form of selective racism concerning "negroes" illustrates, at best, a case of "partial enlightenment" (in the sense being distinguished).

A second modification concerns the possibility that a person x be enlightened about some subject matter M but not about some other subject matter M* (say, they are fully or partially enlightened about the science of gravitational attraction but not fully or partially enlightened about political matters such as republicanism). It is a commonplace observation that some people are enlightened about some subject matter M at a time but not enlightened about other matters such as M*; and yet other people are not enlightened about M at all. Note that all of this can vary over time.

Further modifications allow that a person's belief B is not a matter of either full, or no, belief; there are degrees of belief D in between to take into account.[16] In addition the degree of belief may be sanctioned by some principles of reasoning or principle of scientific method R.[17] Clearly people can differ in the respects and the degree in which they are enlightened.

[16] Here one could adopt an account, found in theories of probabilistic degrees of belief, as to how D is to be understood. D can vary on a scale from 0 to 1.

[17] Perhaps this could be expressed more strongly; it is not just that a person's beliefs are sanctioned by some principles of rationality but a person's actually holds the belief on the basis of the sanctioning principles. Being so enlightened is more strenuous in requiring the actual use of principles of reason in belief formation. Being unenlightened would then be accompanied by forming beliefs dogmatically without any appeal to principles like R.

This suggests at least seven parameters in terms of which enlightenment can be assessed: <a person x in a society S at a time t, a set of beliefs and values B held by x about some subject matter M, some principles of belief assessment R employed by x, and some degree D to which B are given credence by x>. Or in short: <x S, t, B, M, R, D>. This gives a finer gradation concerning enlightenment; having an enlightened attitude to matters is not an all-or-nothing affair. Importantly as x and t vary (within S) the attempt to find the incidence of beliefs B about M in S will result in a scatter of individuals who are enlightened to some degree; but this will shade off into a scatter of individuals who lack any such beliefs - the unenlightened. As indicated this scatter can vary over time and place; determining what is the scatter is a matter of empirical science.

The epidemiological approach taken here shows that one cannot talk in a general way about "The Enlightenment"; this is part of the inflation of the term 'Enlightenment' and its denotational obscurity. Rather there is just the social scatter of the property of being enlightened and unenlightened with respect to people. Perhaps with some charity, the term 'Enlightenment' can be understood on some occasions of its use to be a shorthand way of referring to this scatter.

2.5 Early Attempts to Define 'Enlightenment': Moses Mendelssohn and Immanuel Kant

In his brief 1784 commentary, Moses Mendelssohn does not really attempt to provide a definition of the term 'enlightenment'; but he makes links between it and other notions such as Culture (Kultur) and Education (Bildung) (though the term 'Bildung' can cover all three concepts). He also makes comments which link nicely with what has been developed in the above sections about the epidemiological scatter of the property of being enlightened.

Enlightenment, he says, concerns more theoretical matters, such as our knowledge and our ability to rationally reflect and to eliminate prejudices. This is said to stand in contrast to culture which is oriented towards more practical matters that can arise in political, ethical and aesthetic contexts. He readily acknowledges the different degrees to which societies can be enlightened; the epidemiology of being enlightened differs between different cultural groups such as Berliners, the English, the Chinese and the Ancient Greeks. He also recognises that enlightenment can come in different degrees: '… the enlightenment of a nation is proportional to (1) the amount of knowledge, (2) its importance …. (3) its dissemination through all estates, (4) its accord with their vocations' (Mendelssohn 1784/1996, p. 55). Each of these four considerations can fit with the above set of parameters for determining the scatter, in any population, of the property of being enlightened.

Mendelssohn also acknowledges the way in which education is important in spreading enlightenment. Education is the main way of providing us with an enlightened view of the world (viz., increasing knowledge and understanding of the world), a critical stance from which to evaluate prejudice, and an appreciation of how rational reflection is involved in both these matters. Here Mendelssohn touches on the significant issue of, given the small scatter of enlightened people compared with the larger scatter of the unenlightened, how the number of the enlightened is to be increased. Since the acquisition of knowledge and understanding lies at the heart of the enlightenment project, education becomes important in increasing the extent and degree of enlightenment in any society.

In contrast, Kant does attempt to say what the enlightenment is; this attempt is commonly cited but not often critically evaluated (one exception is Bittner 1996). Kant tells us that the motto of the enlightenment is: '*Sapere aude!* Have the courage to use your *own* understanding!' (Kant 1784/1996, p. 58). As has been said above, understanding and explanation are two proper goals of the epistemic enterprise associated with enlightened thinking. We can all agree that each person, when they can, ought to autonomously employ their own powers of reason in thinking, in constructing explanations and forming their understanding of some subject matter.

Importantly the injunction rules out (1) appeal to authorities (such as religious or monarchical), socially sanctioned traditions, habits and conventions so that epistemic democracy prevails. Kant also emphasises two additional points when he talks of (2) courage, which might well have to be employed in (3) the use of ones' own understanding rather than that of another. These three points are emphasised in what can be taken to be Kant's account of 'enlightenment': '*Enlightenment is mankind's exit from self-incurred immaturity*. *Immaturity* is the inability to make use of one's own understanding without the guidance of another' (*loc. Cit*.).

A number of points need to be made about Kant's account. First, the definition (if that is what it is) given by the injunction '*Sapere aude'* is almost content-less. As important as the injunction is, and although it states that individuals should 'own' their beliefs and not be swayed by mere authority, it does not tell us anything about the actual beliefs and values that an enlightened person ought to entertain or reject, for example, along the lines of the eight cardinal points listed by Israel (modified or unmodified).

Second, one might summon up one's courage to have beliefs with some content but miscalculate what the proper use of one's understanding ought to be. So, something normative has to be added to using one's understanding to ensure that it is a *proper* use so that the products of one's understanding bear some relationship to the truth.

Thirdly, one might well dispute whether any immaturity[18] one suffers from is self-inflicted so that one is unable to make use of one's understanding without the

[18] Some argue that part of the problem in understanding Kant here is with the use of the English term 'immaturity' which commonly translates a German term which has legal overtones not present in the English. Thus the German term can apply to the legal status of minors who do not have certain kinds of responsibilities; but this is not the necessarily the case with the English 'immaturity'.

help of another. One's inability to use one's own understanding may not be self-inflicted and could well be due to other factors outside one's control such as lack of the right education, lack of training to acquire the right skills, lack of opportunity during one's life, and so on.

Fourthly, one should not make the inference that there was a prior stage in which one was mature and then later one is immature (whether it is one's own fault or not) and that one might try to recover the earlier phase of maturity; there might well be no such earlier phase to recover.

Finally, is Kant saying that we ought to put no, or very little, weight on the judgements of others in forming our own beliefs and that always we ought to maximize our own judgmental autonomy? For an enlightened outlook Kant says that we need to make a public use of our reason in all matters. In contrast there are those who tell us not to. Thus the tax collector says: 'Don't argue, just pay. The clergyman says: 'Don't argue, just believe'. And so on.[19] Certainly the injunction '*Sapere aude!'* rules out such cases. But would it rule out the following case from science (rather than religion)? Suppose that a scientist, or Isaac Newton himself, says, pointing to *Principia*, Book III on gravitational attraction, 'Don't argue; just believe this stuff on gravitational attraction!'

We lay people often take what scientists say about their field as authoritative. Moreover scientists in one field (say, genetics) take what other scientists in another field (say, plasma physics) on authority and do not think through the other's science. In general a scientific claim that p (say, about Newtonian gravitation) is taken on trust by others who do not work in the field. And they take it on trust because of the authority of the scientist (after all it is Isaac Newton!), or the authority of the book or journal in which the claim that p is published; and so on. In such cases there is an authoritative person who offers us expert testimony.[20] Standardly in such a case we do not have to argue for ourselves all the ins and outs with some Newton about his theory but simply accept matters on his word. But if one simply takes on board Newton's claims as a matter of expert testimony does it follow that one is immature in some way, as Kant might be understood to claim?

What this example shows is that we can separate Kant's connection between self-incurred immaturity and the guidance that another can provide without fully using one's own understanding. Importantly in education a student can accept such guidance without being self-incurably immature, as in the case of coming to know on the basis of testimony. Kant might well be asking for too much in requiring that the light of reason shine in all cases of knowing. After all we do get much of our knowledge from expert testimony without reckoning we are immature in some way. But it should always remain an open possibility, as Kant indicates, that we also come to know matters, such as Newton's theory of gravitational attraction, on the basis of the exercise of our own powers of reason. This is an aspect of epistemic democracy (see Sect. 2.2) which is at the core of Enlightenment ideas and ideals.

---

[19] See Kant 1996, p. 59. Kant talks of our freedom to use public reason in not following these injunctions.

[20] On expert testimony see Gelfert 2014, especially Chapter 9.

2.6 Some Modern Critics of "The Enlightenment"

(a) John Gray

There is a general tendency found in several contemporary critics to want turn off the lights of "The Enlightenment". Rather than cast light on the world it has been claimed to be responsible for some of the dark episodes of recent human history from colonialism to imperialism, anti-Semitism, the Holocaust, racism, and the like. Thus John Gray wants to tell us: 'The role of the Enlightenment in twentieth-century terror remains a blind spot in western perception' (Gray 2008, p. 50). One can take this to be a causal claim saying that "The Enlightenment" has been casually responsible for some acts of twentieth century terror - though we have failed to notice this. Further on he tells us: 'The Enlightenment played an indispensable role in the development of Nazism'.[21] Indispensability is more casual talk. Thankfully Gray does not think that the Enlightenment was causally involved in *all* twentieth century acts of terror, the case of the 1994 massacre in Rwanda being an exception he mentions. But he does allege there is a causal role of "The Enlightenment" in bringing about some twentieth century acts of terror, or the Nazis.

Contrary to Gray, many would find it hard to envisage how Kant's directive '*Sapere aude!',* viz., 'employ one's own understanding!', or Israel's eight cardinal points of Enlightenment doctrine (see Sect. 2.1), could have been responsible for either terror or Nazism. Gray's remarks are fatuous in an important way. He talks of "The Enlightenment" as if it had causal powers to bring about things. But this is a category error due to the inflated use of language. We have noted in Sect. 2.4 that it is hard to determine what the denotation of the abstract name 'The Enlightenment' is. Perhaps it refers to period of time, say from 1660 to 1790. But periods of time have no causal powers. Nor can the eighteenth century "Enlightenment" make a leap over time to causally affect the Nazis of the twentieth century. Perhaps it refers to some eighteenth century doctrines; but again, propositional doctrines, in themselves, have no casual powers.

The suggestion made in Sect. 2.4 about the epidemiology of beliefs and values held by people in some society over time might bring us closer to the right kind of ground for the casual powers allegedly at work here; it is people and the beliefs on which they act that have causal powers. Putting matters this way turns on the important distinction between a group of people who were enlightened (they adopted something like the eight doctrines listed by Israel) and the complementary group who were unenlightened (either they had never heard of Israel's eight doctrines or, if they had, they were counter-enlightenment people who rejected them).

[21] See chapter 2, 'Enlightenment and Terror in the Twentieth Century' in Gray 2008, p. 78. Again on p. 78 Gray tells us that 'Nazi ideologues picked up from … Counter-Enlightenment thinkers whatever they found useful – as they did with the thinkers of the Enlightenment'. But Gray also speaks of '… a Nazi state which spurned the Enlightenment and all its works …' (Gray 2002, p. 101). Doing both of these seems impossible, even for the Nazis.

Here another distinction mentioned in Sect. 2.4, but not noticed by Gray, becomes important: it is Kant's distinction between "living in an enlightened age" (we do not) but "living in an age of enlightenment" (we do because there are some enlightened people, however few). In this context, the reference of Gray's use of the term 'The Enlightenment' remains quite obscure. We can ask: which group, the enlightened or the unenlightened, might be the best candidate of the alleged causes of twentieth century terror or the Nazis? One would have to attribute a great deal of cognitive dissonance to the enlightened if they are to be deemed causal agents which bring about terror or Nazism.

The above merely addresses the question of what is the alleged casual power at work in these cases of terror, or the rise of the Nazis. It does not yet say whether the supposed casual power actually brings about the alleged effects. The problem with claims of the sort made by Gray and others is that there is no investigation into what are the cause-effect relations that are supposed to hold that would rule out merely accompanying features which are not causes. That there are enlightened people who hold enlightenment doctrines and that they are contemporaneous with people who do not hold or reject enlightenment doctrines (some of whom are agents of terror or Nazism), seems to go unnoticed in vague all-encompassing talk of "The Enlightenment" as some kind of causal power. One would have to show which of the enlightened and the unenlightened is casually responsible for terror or the Nazis; but even this much is not done. What we have are obscure and untested claims about causal relations in which no care has been taken to separate out genuine causes of particular events from spurious accompaniments. This is bad science. But this is one way in which causal claims about the supposed obnoxious effects of "The Enlightenment" get their currency.

Gray tells us about one of the sources of his claims about the rise of the Nazis: 'The argument advanced by some members of the neo-Marxist Frankfurt School, which says that Nazism is a logical development of Enlightenment thinking, is much overstated; but there is more than a grain of truth in it' (Gray 2008, p 78). Here the reference is to the 1944 work of Horkheimer and Adorno, *The Dialectics of Enlightenment*. If Nazism were to be a *logical* development of a certain kind of enlightenment thinking, then that would be to misuse the notion of logic and to confuse it with causation. Happily, this is said to be an overstatement; so we can pass over this claim. But it is left to us to search out what grains of truth we have been offered. Alas, the grains are meagre pickings. Horkheimer and Adorno wrote their book towards the end of WWII in exile in California. They wished to explain the rise of the Nazis in Germany and the Enlightenment is invoked to that end. How this explanation is supposed to work remains obscure or contestable.

(b) Max Horkheimer and Theodor Adorno

In the 'Introduction' to their book *The Dialectics of Enlightenment*, Horkheimer and Adorno summarize their final chapter 'Elements of Anti-Semitism: The Limits of Enlightenment' as follows: 'The argument and thesis of "Elements of Anti-Semitism' is concerned with the actual reversion of enlightened civilization to barbarism' (Horkheimer and Adorno 1994 pp. xvi-xvii). Though seven theses are advanced about the nature of anti-Semitism, nothing substantial is established to causally connect a reversion of "enlightened civilization" to anti-Semitic and Nazi barbarism with "The Enlightenment" supposedly invoked as the temporally distant cause.[22] Again as in the case of Gray, lack of clarity about the reference of 'The Enlightenment' does its job of obfuscation. All three commentators ride roughshod over Kant's subtle distinction between "living in an enlightened age" and "living in age of enlightenment".

One commentator, James Schmidt, finds there is hardly a connection at all between "The Enlightenment" and Nazism owing to the broad way in which Horkheimer and Adorno understand 'The Enlightenment':

> The conception of enlightenment the book elaborated lacked historical specificity and its account of Nazi genocide ultimately made the choice of victims appear as contingent. The costs incurred by both these points should not be underestimated.
>
> In the account offered by Horkheimer and Adorno, "enlightenment" has been defined so broadly as to make it virtually identical with the attempt to master nature through instrumental reasoning. As a consequence, any hope of understanding what was historically specific to the eighteenth-century Enlightenment is lost. (Schmidt 2000, p. 97)

There are two objections here. The first is the familiar point that the referent of 'Enlightenment' is obscure. The second is a new, surprising, point: Horkheimer and Adorno claim that the use of instrumental reasoning to obtain mastery defines 'The Enlightenment' (and that this leads to a disaster for the Enlightenment – a claim to be evaluated shortly). But they give the game away when they refer to non-enlightenment figures such as Francis Bacon, and Odysseus (!), as users of instrumental reasoning. In fact humans have used such reasoning ever since humans began to think. So, such reasoning cannot be a defining characteristic of "The Enlightenment".

Instrumental reasoning is not specifically listed in Israel's 8 cardinal points; but let us not quibble about whether or not such reasoning is to be found there. (It would be in an expanded version of Israel's point (1) as suggested in Sect. 2.2, but other kinds of rationality are covered in point (1) than just instrumental reasoning.) Importantly Israel lists much more in his eight cardinal points which emerged in the eighteenth century Enlightenment period, and are characteristic of it. These items should be invoked if claims are to be made about any casual connection between the Enlightenment and anti-Semitism or Nazism. But it hard to see how any of these, such as toleration, equality, freedom of thought, liberty, equality, republicanism, etc., could in any way be casually responsible for anti-Semitism or Nazism. They in fact count against any such casual connection.

Horkheimer and Adorno have bigger fish to fry. They begin their book by telling us: 'In the most general sense of progressive thought, the Enlightenment has always aimed at liberating men from fear and establishing their sovereignty. Yet the fully enlightened earth radiates disaster triumphant' (*ibid*., p. 3). And they speak of 'the

---

[22] The seven theses to be found in 'Elements of Anti-Semitism' is usefully discussed in Schmidt 2000 in a section entitled 'Projection and Anti-Semitism', pp. 91–97.

indefatigable self-destructiveness of the enlightenment' (*ibid,* p. xi). To emphasise this they also tell us of '… the first phenomenon for investigation: the self-destruction of the Enlightenment' and add that '… the actual historic forms – the social institutions – with which it [The Enlightenment] is interwoven, already contains the seed of the reversal universally apparent today' (*ibid.*, p. xiii). These and other like passages spell out the main idea behind the title of their book *Dialectic of Enlightenment*. There is a *dialectic* at work in the Enlightenment; this is said to be a contradiction or, more metaphorically, something that contains the seed of its own destruction or transformation into something else. The emergence of anti-Semitism is, allegedly, just one aspect of the working out of these dialectical tensions.

Talk of a "dialectic" at work has always been obscure with many resisting such talk; they rightly ask for a more specific account of what are the causes at work which have supposed incompatible tendencies. But it can also be away of obfuscating what one wishes to talk about. Marx himself was not above this, and in fact says as much in a letter to Engels when he temporarily took over his job of newspaper commentator on Indian affairs when Engels fell ill: 'It's possible that I shall make an ass of myself. But in that case one can always get out of it with a little dialectic. I have, of course, so worded my proposition as to be right either way.'[23] One might well suspect that Horkheimer and Adorno have more than a little of Marx's dishonest cunning in using dialectic to get out of intellectual trouble and to be right regardless whatever they say.

It is hard to determine what dialectical contradiction lies at the heart of "The Enlightenment" which contains the "seeds" of its own destruction. But it is generally supposed to be due to the dominant role of instrumental reason to the exclusion of other forms of reason in our coming to master nature. The Elizabethan Francis Bacon (hardly an Enlightenment figure though he is prominent in the so-called 'scientific revolution'), is excoriated for promoting this kind of thinking in his advocacy of science. In summing up Bacon's alleged stance Horkheimer and Adorno tell us:

> What men [sic] want to learn from nature is how to use it in order wholly to dominate it and other men. That is the only aim. Ruthlessly, in despite of itself, the Enlightenment has extinguished any trace of its own self-consciousness. The only kind of thinking that is sufficiently hard to shatter myths is ultimately self-destructive' (Horkheimer and Adorno 1994, p. 4)

In this context they also cite Bacon's claim that 'power is knowledge'.[24] Though this is a common view it is hardly compelling. First, it supposes that all principles of reasoning are instrumental in character which, we may suppose, is of the form 'if

[23] A letter by Marx to Engels, 15 August, 1857; see Marx-Engels *Collected Works Vol 40* (1983) p. 152.

[24] This is a slogan, often advocated by Foucault, which should be resisted. Most books on epistemology do not claim that the definition of knowledge involves power. In fact they do not even mention it, since they think that the view is so mistaken it is not worth noting. But of course if you know something then your powers of action can be enhanced. But this has nothing to do with the nature of knowledge itself; at best it is a possible consequence.

you want V then do X'. These are means-ends claims where 'X' is some procedure or action to be carried out and 'V' is something one might want, or value, or it might even be a value itself.[25] But as has been suggested in Sects. 2.2 and 2.5 in which principles of scientific reasoning are mentioned, in particular Newton's *Rules of Reasoning in Philosophy*, these are not instrumental in form; they are categorical. In fact in science one finds both instrumental claims alongside categorical claims. And in some of these categoricals the value might be truth itself; and X tells one how to arrive at truth. This is hardly an instrumental value to be excoriated.

Horkheimer and Adorno have a very one-sided and blinkered view of both science and its methods in ignoring categorical claims or the values that can enter into instrumentalities; but this is not uncommon in theoreticians of their ilk. For this reason their considerations about the dominance of instrumental reasoning fails to make its point.

A second unacceptable claim is that domination of nature and other men is 'the *only* aim' that instrumental principles can have. True, people do wish to finds means (some provided by science) to dominate others. But this is not always the case and one can have instrumentalities that involve aims other than domination, such as those mentioned in Israel's cardinal points which express values such as equality, secularism, toleration, freedom, and the like. Though there are a lot of instrumentalities of domination to be noted, they are not the only instrumentalities and they have competitors with other values. This is something that most advocates of enlightenment values would recognise in their struggle against the absolutist tendencies of the churches, monarchies and governments of the time. And it is something we should recognize *pace* Horkheimer and Adorno.

Thirdly, there is the unacceptable claim that, as a result, the Enlightenment is somehow self-destructive. This *might* be so if the instrumentalities are *only* directed at dominance. But they are not. As just mentioned the social and ethical values espoused by enlightenment thinkers also involve values such as equality, secularism, toleration, freedom, republicanism and the like. These are ignored by Horkheimer and Adorno.

At the end of their book Horkheimer and Adorno tell us: 'Enlightenment which is in possession of itself and coming to power can break the bounds of enlightenment' (p. 208). Characteristically this is a somewhat obscure remark about an Enlightenment "in possession of itself" which somehow "breaks its own bounds". (This occurs when, presumably, issues of equality, secularism, toleration, freedom are given prominent recognition). If such a kind of Enlightenment is possible, then it would appear to be in contradiction with claims they make at the beginning of the book about 'the indefatigable self-destructiveness of enlightenment' in which this possibility appears to be ruled out. No dialectical wriggle can get them out of this contradiction; rather they must seriously modify the core of the dialectical claim

---

[25] It is important to note that in instrumentalities of the form mentioned, V can be a value itself, and not merely some goal or end that one might wish whatever its value. Horkheimer and Adorno seem not to recognise this point and reduce all instrumentalities to means-ends claims whatever the end.

about Enlightenment's self-destructiveness. And this they appear to do when, as some commentators suggest, they had planned to write a sequel which would counteract the negative view of *Dialectic of Enlightenment* with a more positive view in a work tentatively called *Saving the Enlightenment*.[26]

It is hard to tell from Horkheimer and Adorno's critique whether there is anything worth saving in "The Enlightenment", contorted as it allegedly is by instrumental reasoning amongst other defects. If there were genuinely a "dialectical contradiction" at the heart of the Enlightenment then there is nothing to write about in any sequel; the Enlightenment is stuck with its alleged internal contradiction (and whatever fate is supposed to follow from this). But that there is such a contradiction is hopelessly obscure. As Marx advises, Horkheimer and Adorno can wriggle out of their predicament with a little dialectic and be right either way.

Do Gray or Horkheimer and Adorno mange to tell us something about the nature of Enlightenment? At best Gray gives us false causal consequences of it. And I leave it to a recent (not unsympathetic) commentator to tell us about Horkheimer's and Adorno's book: 'The few mentions of the original libertarian and emancipatory nature of the Enlightenment within the volume were hardly adequate to counterbalance its apocalyptic tone and unsubstantiated indictments, or the authors' unilateral pronouncements according to which "Enlightenment is as totalitarian as any system" (Horkheimer and Adorno, p. 24)' (Ferrone 2015, p. 33).

2.7 Conclusion

Here just three of the many critics of "The Enlightenment" have been mentioned. But there is now an academic industry hard at work discrediting the Enlightenment by showing that it is intimately bound up with the Nazis, the holocaust, capitalism, colonialism, universalism in education – you name it! To deal with all of these would require much more space than is available here. But many of them make Gray's false assumption that if something is coincidental with "The Enlightenment" then "The Enlightenment" must be the cause of it. To make this error one must not only have a poor idea of how casual connections are to be tested; also one has failed to see that talk of "The Enlightenment" is often quite obscure and that its referent is unclear. By introducing the idea of the epidemiology of enlightenment one can then begin to see how excessive focus on a nominalization of what is more properly adjectival can lead one astray. Talk of 'The Enlightenment' can be a convenient shorthand; but it comes at the cost of taking the nominalized name at face value and assuming that there is a definite "object" to be spoken about. The epidemiology of being enlightened tells us what are the real facts hidden behind the veil of a nominalizing abstraction.

---

[26] On this supposed sequel see Schmidt 2000, p. 101. It seems as if little of it was actually written down.

References

Bittner, R. (1996). What is enlightenment? In Schmidt (Ed.) (1996) pp. 345–358.

Brickhouse, N. W. (2001). Embodying science: A feminist perspective on learning. *Journal of Research in Science Teaching, 38*(3), 282–295.

Bristow, W. (2010). Enlightenment. In E. N. Zalta (Ed.) *The Stanford Encyclopedia of Philosophy*. URL = http://plato.stanford.edu/entries/enlightenment/. Accessed 26 Apr 2016.

Cassirer, E. (1951/1932). *The philosophy of the enlightenment*. Princeton: Princeton University Press.

Coyne, J. A. (2015). *Faith vs. fact: Why science and religion are incompatible*. New York: Viking.

Ferrone, V. (2015). *The enlightenment: History of an idea*. Princeton: Princeton University Press.

Gay, P. (1967). *The enlightenment: An interpretation: Volume 1, the rise of modern paganism*. London: Weidenfeld and Nicholson.

Gay, P. (1970). *The enlightenment: An interpretation: Volume 2, the science of freedom*. London: Weidenfeld and Nicholson.

Gelfert, A. (2014). *A critical introduction to testimony*. London: Bloomsbury.

Goldstein, R. (2015,May). Don't overthink it. Review of Matthew B. Crawford, *The world beyond your head: On becoming an individual in an age of distraction*. In *The Atlantic monthly* (pp. 50–52). Boston: The Atlantic Co.

Gould, S. J. (1999). *Rocks of ages: Science and religion and the fullness of life*. New York: Ballantine.

Gray, J. (2002). *False dawn: The delusions of global capitalism*. London: Granta Books.

Gray, J. (2008). *Black mass: Apocalyptic religion and the death of utopia*. London: Penguin.

Habermas, J. (1990). *The philosophical discourse of modernity: Twelve lectures*. Cambridge, MA: The MIT Press.

Honneth, A., McCarthy, T., Offe, C., & Wellmer, A. (Eds.). (1992). *Philosophical interventions in the unfinished project of enlightenment*. Cambridge, MA: The MIT Press.

Horkheimer, M., & Adorno, T. (1994/1944/1947). *The dialectics of enlightenment* (Cumming J., Trans). New York: Continuum.

Hume, D. (1985). Of national characters. In E. F. Miller (Ed.), *David Hume: Essays moral, political and literary* (pp. 197–215). Indianapolis: Liberty Classics.

Israel, J. I. (2006). *Enlightenment contested*. Oxford: Oxford University Press.

Israel, J. I. (2011). *Democratic enlightenment*. Oxford: Oxford University Press.

Kant, I. (1996/1784). An answer to the question: What is enlightenment? In J. Schmidt (Ed.) (1996) pp. 58–64.

Locke, J. (1689/2010–15). *'Toleration' (or 'First letter on toleration')* translated by Jonathan Bennett. http://www.earlymoderntexts.com/assets/pdfs/locke1689b.pdf. Accessed 20 Apr 2016.

Marx, K., & Engels, F. (1983). *Letter of Marx to Engels, 15 August 1857. Collected works volume 40. Marx and Engels 1856–1859*. London: Lawrence and Wishart.

Matthews, M. R. (2015). *Science teaching: The contribution of history and philosophy of science*. New York: Routledge.

Mendelssohn, M. (1784/1996). *On the question: What is Enlightenment?* In Schmidt (Ed.) (1996): pp. 53–57.

Pocock, J. G. A. (1999). *Barbarism and religion: Volume 1, the enlightenments of Edward Gibbon, 1737–1764*. Cambridge: Cambridge University Press.

Schmidt, J. (Ed.). (1996). *What is enlightenment? Eighteenth-century answers and twentieth- century questions*. Berkeley: University of California Press.

Schmidt, J. (2000). Genocide and the limits of enlightenment: Horkheimer and adorno revisited. In Stråth and Kaye (Eds.) (2000), pp. 81–102.

Shimony, A. (1997). Some historical and philosophical reflections on science and enlightenment. In L. Darden (Ed.), *Proceedings of the 1996 PSA meeting* (pp. S1–S14). East Lansing: Philosophy of Science Association.

Sperber, D. (1996). *Explaining culture: A naturalistic approach*. Oxford: Blackwell.

Stråth, B., & Kaye, J. (Eds.). (2000). *Enlightenment and genocide, contradictions of modernity (philosophy and politics, volume 5)*. Brussels: Peter Lang International Academic Publishers.

Chapter 3
The Enlightenment Tradition and Science Education in Turkey

Deniz Peker and Özgür Taskin

3.1 Introduction

The original Enlightenment tradition in Europe emerged as a reaction to the Catholic and Protestant churches' dogmatism and feudal aristocratic oppression in quest for a more rational and sceptical worldview, and a freer society. The Enlightenment ideology projected a broad range of notions such as universalism, objectivity, rationality, empiricism, scientism, anti-revelationism, naturalism, utilitarianism, optimism and independence (Matthews 2015a, Chap. 2). In the interest of space, we limit our examination of the enlightenment mostly to the development of the modern and secular Turkish state and its educational institutions beginning from the reformation of medieval Ottoman Empire structures (eighteenth century) to contemporary Turkish society.

The original Enlightenment was a product of social, political, cultural, philosophical and economical influences in a given time frame (roughly seventeenth and eighteenth centuries) and geography (Western Europe). For instance, the scientific revolution of the seventeenth century prepared the way for the eighteenth century Enlightenment movement. So also did the religious wars that made questionable the entrenched prestige and moral and intellectual authority of the church. The conditions that brought about the Enlightenment were unique to its time and place. Thus beyond the centre of the enlightenment, at the periphery, different cultures went through different processes of enlightenment influenced by their own cultural, political and material conditions.

D. Peker (✉)
Department of Teacher Education, Columbus State University, Columbus, GA, USA
e-mail: peker_deniz@columbusstate.edu

Ö. Taskin
School of Education, Ondokuz Mayis University, Samsun, Turkey
e-mail: omuozgurtaskin@gmail.com

M.R. Matthews (ed.), *History, Philosophy and Science Teaching*, Science: Philosophy, History and Education, DOI 10.1007/978-3-319-62616-1_3

Historical analyses show that beyond Western Europe each enlightenment trajectory is unique in the way it adopts, transforms, or redefines the original enlightenment ideas (Outram 2013). It is argued that the enlightenment of the non-West is a process of appropriation in which the "transferred" ideas from the West create a new, emerging discourse to accommodate new ideas into existing schemas (Patiniotis and Gavroglu 2012). Patiniotis and Gavroglu argue that this new discourse is the best way to overcome the local constraints because new ideas are not transferred into a vacuum; rather they replace or modify existing ways of thinking, reasoning or organizing knowledge. Thus this discursive negotiation phase is a necessary element to overcome an initial rejection of ideas and creates a context for their new legitimization.

Given these assumptions, we will provide a treatise of Ottoman-Turkish enlightenment, paying particular attention to the unique aspects of the Ottoman and Turkish case, which is different in many respects from Western Europe. For clarity, we reserve the words West and Western Europe to refer to countries beyond the west of the Ottoman Empire borders even though the Ottoman Empire had territories in Europe. Our purpose is to show, beginning from the eighteenth century Ottoman Empire, how the enlightenment ideas were initially perceived by the Ottomans as part of their long-standing modernization efforts and continued through the more systematic ways during the late Ottoman, early Turkish Republic, and finally modern Turkey. First, we will provide the context for the Ottoman case by describing its unique characteristics where the battles of enlightenment took place. We will then provide accounts of important historical events in the Ottoman-Turkish enlightenment trajectory. Finally, we will provide a conclusion to our analysis.

3.2 The Ottoman Context

The enlightenment tradition in modern Turkey cannot be understood without first examining the enlightenment tradition in the late Ottoman Empire. The Ottoman Empire had different societal dynamics than Western Europe; thus, to understand the enlightenment tradition in the Ottoman Empire (and subsequently, Turkey) one needs to pay attention to these differences. These differences are related to religion, state-religion relationships, scientific and intellectual inheritance, and economic variables.

First, the Ottoman Empire was an Islamic state, even though the empire was home to many non-Muslim groups. The ruling Sultan (Padisah) of the empire was also the Caliphate for the Islamic world, meaning that he was the direct representative of God in the world. However, the Caliphate did not assume any divine or prophetic role; nor did he have any particular religious status other than being at the highest position of protecting the Islamic order. The power of the Sultan was only limited to Sharia, the Islamic Law (Berkes 1998).

The Ulema was the religious authority, composed of the corps of learned men of religion who ensured that the laws and executions of the ruling Sultan were in accordance with Sharia. Members of the Ulema were trained in madrasas that were in essence, higher education institutions teaching theology and Islamic law. The Ulema had three classes within itself: imam (minister of religion), mufti (juriconsult), and kadi (judge). All of these were involved in regulating the relationship between the religion and many aspects of social life based on Islamic laws. However, the roles of muftis were particularly important because they were responsible for the administration of justice and determined whether the Sultan's laws and actions are in accordance with Islam. The highest ranking mufti was named Seyhul-Islam (or Shayk al-Islam), who was appointed by the Sultan but who had the power to depose a Sultan if they were not acting in accordance with Sharia. Seyhul-Islam's authority was almost equal to Sadrazam (Grand Vizier) who had the highest authority in state affairs below the Sultan. Seyhul-Islam declared official statements, called fetvas, on legal and technical matters but also about declarations of war as well as new innovations such as the use of coffee or tobacco (Berkes 1998). This model of Islamic jurisprudence as part of the state still continues, though to a much lesser degree in the Republic of Turkey. The Department of the Affairs of Piety (Diyanet) issues fetvas on personal religious matters although it does not directly interfere with the state affairs (Gulalp 2005).

When comparing the enlightenment tradition in Europe and Islamic societies, there are a few differences between Christianity and Islam that are worth mentioning. First, Islam does not have the same ecclesial institutions and priestly class as does the bulk of Christian tradition. In Christian Europe, the church and the state were, for the most part, separate but allying forces, typically defending one another.[1] Whereas in Islamic societies, the church and the state were fused; there was not a separate church institution (Berkes 1998; Davidson 2006). The Ulema in the Ottoman State was more of a temporal and official body, unlike the Catholic or Orthodox clergy who had a spiritual corps organized through the church, but often did not have an official position within the government. Thus, as a state authority, Ulema's prime function was to protect the order (nizam) against any change or reform. In such a traditionalist system, there was no room for change through the agency of state. Berkes argues that Ulema's influence was so strong that those who proposed a reform or change had to say that they were doing so in order to restore the order (nizam). It is important to note that during the Ottoman times there were major reform movements with similar cognates, such as the Tanzimat, the New Nizam, and Nizamat-I Essasiye (Berkes 1998).

A second difference between Islamic and Christian societies relates to their association with science. With some qualification, the Enlightenment was a clash between the new science and Christianity – both Catholic and Protestant.[2] Both Christianity and Islam were in harmony with science in the medieval times or what

[1] The distinction was very blurred in the Papal States and in Calvin's Geneva, and less blurred elsewhere. In England, France and Spain, there were 'established', state-sanctioned and controlled church structures that considerably blurred the church/state division.

[2] This is a major and contested historic thesis, but see, for instance, Gay (1970) and Israel (2001, 2006, 2011).

is known as the Golden Age of Islam. Tensions came later in the seventeenth century when modern science began to emerge in Europe. Even though some thinkers still argue that there is a harmony between Islam and modern science (Altwaijri as cited in Davidson 2006), this is rather superficial, according to Edis and BouJaoude (2014), because Islam has a conflict with materialism that rejects supernatural forces operative in nature. The conflict between religion and science in the Ottoman Turkish intellectual life did not start until the end of the nineteenth century when Western ideas of positivism and biological materialism emerged (Ihsanoglu 2006).

According to Ihsanoglu (2006), the Ottomans initially saw themselves superior to Europe and the autarchic structure of governance did not allow for much transfer of scientific and technological knowledge between governments. While the Ottomans selectively adopted new developments, when the Empire lost its political and military edge against Europe, such transfer of scientific and technological knowledge increased, especially in the military area. Ihsanoglu indicates that the Ottomans were mainly interested in the final products and applications of scientific and technological achievements, rather than the processes that brought them about – a situation very similar to many parts of the contemporary world. The Ottomans were not interested in theory, experiment, and the research aspects of science. They lacked the experimentalist tradition and thus struggled to accommodate logical methods and novel empirical knowledge (Kucuk 2012). As such, pre-modern science remained as a collection of isolated facts, often mixed with superstitious beliefs (Edis and BouJaoude 2014). It was not until in 1900 that research became a part of the Ottoman scientific culture with the establishment of the first modern university replacing madrasas.

Kucuk (2012) points out that the original sceptical movement that epitomized seventeenth century philosophical thinking was absent in Ottoman circles. For instance, Spinoza and Bayle were not known to the Ottomans; and, ironically, Ottoman scepticism toward religion came from religious thinkers themselves rather than philosophers. For instance, Akkach (2007) notes that while in Christian Europe the battle between reason and faith resulted in favour of reason, within the Muslim Middle East, faith and reason had a dialectical relationship. Akkach further elaborates his point by describing four groups of thinkers who represented rational thinking in Ottoman culture during the seventeenth and eighteenth centuries. These were (a) scientists, (b) science-oriented scholars and entrepreneurial officials who promoted the public profile of science in Ottoman society, (c) religious scholars with puritanical views who thought that Islam should free itself from mystical and superstitious beliefs, and (d) another religious group of scholars who advocated for the expansion of the rational scope of Islamic faith while increasing receptiveness to new ideas and a sense of tolerance.

Thus, just like the way the church and the state are fused in Islam, it appears that reason is fused with faith at least during the early enlightenment period. This alludes to what Israel (2006) defines as moderate (or conservative) Enlightenment, as opposed to radical Enlightenment. According to Israel, radical Enlightenment is characterized by the purest sense of the enlightenment ideal represented by reason alone. Alternatively, moderate enlightenment is represented by reason combined with faith and tradition. Between the two, the moderate form was more dominant and accepted throughout the Ottoman Empire during the early Enlightenment period (Kucuk 2012).

Before being exposed to modern western science, science during the classical period within the Ottoman Empire was practiced in madrasas (religious institutions where Islamic studies were conducted). Ottoman scientific activities mainly focused on mathematics, astronomy, medicine and physics. One of the earliest contributions came from Qadi Zadeh al-Rumi (d. 1440) who wrote *Commentary on the Compendium on Astronomy* and *Commentary on The Fundamental Theorems (in Mathematics)*, in Arabic. His tradition continued through his students including Ali Kuscu (d. 1474), who was from Turkestan. Still, some of the twelve books he wrote on astronomy (mostly in Persian) were widely taught in Ottoman madrasas (Ihsanoglu 2006).

In medicine, one of the most significant contributions was made by Serefeddin Sabuncuoglu (1385–1470?) who wrote a surgery textbook entitled *Imperial Surgery*, in Turkish. The book was the first of its kind with descriptions of specific surgical procedures accompanied by colourful miniatures as well as the first known depictions of female surgeons (Bademci 2006).

Perhaps one of the most interesting cases in the history of Ottoman science is Taqii-al-Din (1520/1525–1585) and his observatory. On the one hand, this case shows how Ottomans were open to new developments and scientific discovery; on the other hand, it shows how fragile these efforts were in a society where theocracy and superstitious beliefs were prevalent. In the Ottoman tradition, since the late fifteenth and early sixteenth centuries the palace had astronomers who were graduates of madrasas. These astronomers prepared calendars, fasting schedules, horoscopes, and determined the most propitious hour for important events such as imperial accessions, wars, the launching of ships, etc. (Ihsanoglu 2006). Taqii-al Din, who came from Egypt, was appointed as the chief Ottoman astronomer early during the reign of Sultan Murad III (1574–1595). A sophisticated, state of the art observatory was built for him that operated between 1574 and 1580. Taqii-al-Din invented the sextant and other astronomical tools to determine equinoxes, and brought many new approaches to determining the positions of stars. Further, he developed more precise methods to determine the time of the Sun's apogee than those of Copernicus and Tycho Brahe.

While Brahe, who was a Danish contemporary of Taqii-al-Din, was able to continue his work within his observatory until his death, Taqii-al-Din's work was cut short because his observatory was ordered to be demolished by Sultan Murad III in 1580. Although historians do not agree on the exact reasons for this, one explanation is that Taqii-al-Din's prediction of favourable success for the Ottoman army (based on his recorded observations of Halley's Comet) did not materialize. However, another important explanation is that the Ulema was suspicious of Taqii-al-Din's activities (believing that such activities might support infidels) and recommended the demolition to the Sultan (Sayili as cited in Akkach 2007). Thus, while Brahe's apprentice, Kepler, further developed Brahe's ideas to propose the laws of planetary motion, Taqii-al-Din did not have the opportunity to refine his ideas, most of which remained vague. Later, the scientific activities in the Ottoman Empire drastically declined, beginning from the seventeenth century, due to the disruption in the economy, the loss of land, and the loss of power in the central authority to support scientific activities (Ihsanoglu 2006).

An important argument about why Islamic nations did not have enlightenment comparable to that of Europe relates to the economic structure of the Islamic societies. According to Davidson (2006), feudalism was the prime mode of production within Europe whereas the Ottoman Empire had a tributary mode of production. The difference between these two modes of production lay in how the economic power over the peasants was exerted by the monarchies within their respective contexts. In Europe, a more decentralized governing structure existed in which monarchs passed some of their authority down to local lords who then exploited the peasants who lived on the land through coercive rent and labour. Davidson argues that this fragmented structured allowed for the development of a capitalist economy because different forms of production relations could exist. On the other hand, in the Ottoman Empire, all agricultural land belonged to the Sultan with peasants as the Sultan's direct tenants. The central state, which did not allow for private ownership of land or different approaches to production, collected taxes directly from the peasants with religion as the source of the political legitimation of this tributary mode (Gulalp 2005).

As the Enlightenment movement was emerging in Europe where capitalism was growing, the Ottoman Empire kept its tributary-based economic structure and it was poorer than Europe (Georgeon 2006; Kucuk 2012). More importantly, the Ottoman Empire, and the subsequently young Republic of Turkey, did not have the significant conditions that led to the Enlightenment such as the Renaissance, seventeenth century scientific revolutions, or the modern wars of religion. Nevertheless the post-War proclamation of the Republic of Turkey, with its modern constitution, was certainly in the enlightenment tradition.

In his work related to the early enlightenment of Istanbul (during the reign of Sultan Ahmed III 1703–1730), Kucuk (2012) describes two mechanisms noted by historians for the spread of the Enlightenment from its Western European origin to different geographies. The first mechanism was through the actors and networks of people that carried the ideals of Enlightenment. The second mechanism was the dispersion of the Enlightenment ideals through the texts that were systematically translated across different domains of inquiry, including literature, politics, philosophy, etc. It appears that both mechanisms were in place during the early Ottoman and Turkish enlightenment period. Many Ottoman-Turkish thinkers visited Western Europe, especially France (Korlaelci 2009), received education, and influenced the political and intellectual life within the Ottoman Empire. Many literary and scientific works were translated to the Ottoman and Turkish languages. For instance, from 1729 to 1928, the year Turkey adopted the Latin alphabet, 3534 books were translated into Turkish (Berk 2007). This tradition continued in the young Turkish republic. For example, Hasan Ali Yucel, a Minister of National Education and one of the important political figures of the early republic, initiated a bureau of translation that translated 496 pieces of world literary classics and philosophical texts into Turkish between 1940 and 1946.

In what follows, we present the Enlightenment tradition by examining some of the key events within distinct historical periods from the late Ottoman Empire to today's modern Turkey while providing cultural, social, and political contexts for these events.

3.3 Eighteenth Century Reforms in the Ottoman Empire

During this period, after losing battles in both military and economical fields, the Ottomans realized that they were not the better of the West in such matters. The Ottoman Empire began losing its land and power beginning with the Treaty of Karlowitz (1699), and subsequently the Treaty of Passarowitz (1718). These treaties mark the decline of the Ottoman Empire, and later resulted in long-lasting Westernization (i.e., modernization) movements which were the precursors for more systematic enlightenment movements culminating in Ataturk's comprehensive reforms that, in many respects, out-enligthened what had occurred politically and culturally in Western nations.

Berkes (1998) defines this period as the "new worldliness" where the spirit of worldliness rose as the interest in secular learning increased; this was true not only for the prosperous elite but also for other classes too. Ottomans were interested in new developments in every area of life including science, philosophy, history, music, and architecture. The period following the Treaty of Passarowitz up to 1730 is called the Tulip Era, where the Ottomans oriented themselves toward the West. During this Tulip Era, Ottomans adopted new tools and technologies including printing press machines, architectural and literary styles, and translated many foreign books into the Ottoman language. Ottoman diplomats were sent to France and other countries to better understand the reasons for the West's success.

The loss of territory took its toll on the empire's economy because tax money that came from local merchants trading with Europe was lost (Gunal 2013). To recover from this economic downturn, the Empire first brought in Western scholars during Selim III's reign (1789–1807) and, later, sent students to the West during Mahmut II's reign (1808–1839). During this period, the opening of new military and civilian schools in addition to the Madrasas was the first attempt to increase the quality of education as well as the Ottoman Army's power. The artillery branch of the army was reorganized and headed (1729) by Claude Alexandre de Bonneval, a French army officer who joined the Ottoman Army and converted to Islam. New naval engineering and army engineering schools were opened in 1773 and 1796, respectively, focusing on building their own artillery weapons. The first science textbook translations were made during this period even though they were for military purposes rather than general education (Gunal 2013).

According to Tekeli and Ilkin (1993), the Ottomans' scientific developments were delayed, fragmented, and selective. For instance, the earliest references to Copernicus were in 1660, and until the beginning of nineteenth century Ptolemy's theories were taught in astronomy courses. However, Galileo and Newtonian laws were adopted earlier for military purposes. It was hard to say that there is a systematic effort for gaining scientific advancements and reforming schools.

While Ottoman ruling elites were trying to understand the West and the characteristics of their institutions that made them successful, non-Muslim communities within the Ottoman Empire had their own enlightenment within their respective communities. The Ottoman Empire occupied a massive land spread over three continents. Within this largely diverse geography and rich ethnic composition, it is hard imagine a unified view of an enlightenment phenomenon for Ottoman societies. Greeks, Armenians, and Jews had their own trajectories of enlightenment on the Ottoman canvas. During 17th and 18th centuries Greek educational institutions were still influenced by the Ecumenical Patriarchate of Constantinople. Beginning with the reform movements within the Patriarchate in 1776, the influence of merchants increased, especially in secondary education (Tekeli and Ilkin 1993). With the increased Greek nationalism, two engineering schools were opened in Bucharest and Jassy. Later in 1803, Greeks established an academy in Ayvalik with a laboratory and library.

Before experimentation and laboratories first appeared in Darulfunun in the1860s, at the beginning of the 1800s, a young Greek scholar Konstantine Kumas was teaching about experimentation, observation, and Kantian philosophy in Greek schools in Izmir. However, the Patriarchate reacted to the secularization of education and these schools were closed in 1819. Another school in Istanbul, Kurucesme, provided education for low income Greek students from the secondary level to the postsecondary, higher education level. This school was also not welcomed by the Patriarchate and, in 1820, was closed during a Greek uprising. The Greek Church feared that their authority over the Greek community was diminishing which was a typical phenomenon among the different churches of the Ottoman society. Still, the Greeks began using the printing press (1627) and there was a growing group of Greek intellectuals questioning the Church's authority.

The Armenian community was also active in their schooling efforts. Armenians used the printing press beginning in 1576. As such, Tekeli and Ilkin (1993) report that Armenians translated works that originated in Vienna and Venice. In the Amlorti Monastery in Bitlis (located in eastern Anatolia province), science courses were taught by the start of the eighteenth century with many Armenian schools opening in many parts of the Empire throughout the early eighteenth century. However, the first known official Armenian school was opened by Midirgic Miricanyan toward the end of the eighteenth century and later this school was converted to a postsecondary higher education institution. Somel (2005) reported that the quality of Armenian schools was better in the western and central parts of Anatolia than eastern Anatolia, which suffered from a scarcity of teachers. By the 1870s, in Anatolia there were about 450 Armenian schools and 80,000 students, while in Istanbul there were approximately 48 schools and 6000 students (Dere 2008).

Although Jewish schools thrived during sixteenth century, they were relatively more stagnant during seventeenth and eighteenth centuries in comparison to Greek and Armenian schools. Tekeli and Ilkin (1993) attribute this to the fact that the Jews lost ground to the Greek and Armenians in the Ottoman Court. Another purported reason for the loss of influence from Jewish schools is the fact that Sabbatai Zevi, a Jew from Izmir, declared himself the Messiah in 1648 and 1666. The resulting spread of mysticism within Jewish society hampered the progression of Jewish schools. Interestingly, while the Jewish people were the first to bring the printing press to the Ottoman Empire in 1492, in the 60 years between 1650 and 1710 they had not published any books. It was not until the second half of the nineteenth century that Ottoman Jews detached themselves from the Western religious communities (Tekeli and Ilkin 1993). During this strict conservative era, the Orthodox Jewish community advised that their members not send their children to Galatasaray High School, one of the oldest educational institutions in Istanbul because it did not observe kosher rules.

The eighteenth century meant an exploration of Western ideas and institutions for the Ottoman ruling class and elite. They realized that change was necessary but also wanted to understand the reasons for the West's continually developing advantage in military and economical areas. Many diplomats were sent to Europe and an extensive flow of Western ideas, tools, knowledge, and ways of living became available. Within this context, the Ottomans were first interested in reforming the military. They realized the importance of mathematics and physical sciences for military success. Several books in trigonometry and natural sciences were translated and, for the first time, printing press machines were used. Ibrahim Muteferikka, a Hungarian war slave who converted to Islam, was the first person to use a printing press among the Ottoman's Muslim community. He had to convince Ottoman Sadrazam (Grand Vizier), Seyhul Islam and the Ulema to use the printing machines. He was able to secure permission for printing only non-religious books.

In the Ottoman Empire, unlike Western Europe, it took until the nineteenth century to have the first constitutional political system. For such a system to be established, medieval estates needs to be dissolved. However, because the religion and state were fused within the Ottoman tradition, there was resistance to such social and political changes for a long time (Berkes 1998). Therefore, the Ulema continued to exert its authority over the acceptability of changes. In time, the Ulema accepted some changes as inevitable necessities of the times. However, when the status quo was threatened by the need for change at the beginning of the seventeenth century, the views among the group of lower ranking Ulema fundamentalist contested most changes as being against Sharia (Berkes 1998). Increasing interest for mysticism and superstition in society, bolstered by fundamentalist views, was the biggest obstacle for rationalism.

Another reason for the growing resistance to change came from the Ottoman resentment of the West due to the unfolding political events at the beginning of the eighteenth century. First, there was a reaction against the West's increased interest in materialist life in a society, where spiritualism had long been the dominant ethos. Second, as the Ottoman Empire was threatened by a rising Russia, it turned her face more toward the West, especially France, which was the strongest power within continental Europe. France and the Ottoman Empire both had conflicts with Russia, and their alliance grew through strengthened diplomatic relationships. The Ottoman Empire granted France several concessions that allowed legal, economical, and other privileges. These concessions to France, along with France's diplomatic encouragement to begin a war with Russia, resulted in more resentment of the West and its Ottoman reformers when the Ottoman Empire lost the war with Russia (1768–1774). As the Ottomans continued to struggle in economic and military areas, they saw Europeans as a threat to their sovereignty and cultural and religious inheritance (Berkes 1998).

3.4 Nineteenth Century Reforms in the Ottoman Empire

During the nineteenth century, while Europe experienced an expansion of bourgeois and proletariat classes with growing industrialization and capitalism, the Ottoman Empire still maintained its mediaeval class composition. Ottomans were still focusing on regulating the relationship between the citizens and the state, especially for the minority populations. Tanzimat Proclamations (1839) and The Ottoman Reform Edict of 1856 are two important milestones of this era. The Tanzimat Proclamations were the first constitutional document in any Islamic country. It stated that a new set of laws will be implemented, although still in accordance with Sharia. These new laws were meant to protect the inviolability of life, property and honour, and were applicable to all citizens, Muslims and non-Muslims alike. Later, the Reform Edict of 1856 further extended the rights of citizens, especially for non-Muslims.

On the other hand, despite the economic and social struggles of the Ottoman Empire, the infusion of scientific and technological knowledge continued, importantly, with a more positive perception of science promoted at least among the ruling elite and intellectuals. By the mid-19th century a growing group of Turkish intellectuals who had been to Europe, or were influenced by European ideas, emerged. This group promoted a new discourse on science and emphasized the familiarity with science as one of the conditions of being a good, patriotic Ottoman (Yalcinkaya 2015). Yalcinkaya asserts that in nineteenth century, one of the most frequently used words within Ottoman texts about the state was "ignorance". It was held that ignorance of the "new knowledge" (science) was the main reason that the Ottoman State was failing; by then the Ottoman ruling class had realized that religious sciences and modern sciences were entirely different realms. In order to prosper in this world, they understood that scientific and technological advancement was necessary. On the other hand, tensions emerged between the ruling class and intellectuals because official documents presented science as a gift bestowed by the Sultan to his subjects rather than knowledge which was a human enterprise accessible to everyone who was interested in it.

Yalcinkaya's work further illustrates how new knowledge (science) was negotiated among the Ottoman elites as "useful" knowledge as they attempted to position science with respect to the old knowledge (religion). Eventually, these discussions brought a turning point during this century in which this new knowledge became associated with Turkish while old knowledge (religion) was associated with Arabic;

meanwhile Turkish nationalism grew, especially among such groups as the Young Ottomans.

Prior to the Tanzimat Proclamations, public education was not on the agenda of reform movements. As a continuation of the army engineering schools that were opened in previous century, several more major schools were opened including a medical school (Tibhane-i Amire) in 1827, a surgery school (Cerrahhane-i Amire) in 1832, a military school (Mekteb-i Harbiye) in 1839, and a veterinarian school (Baytar Mektebi) in 1841; these were later followed by agricultural, welding, and forestry schools. In 1859, the first public administration school, Mekteb-i Mulkiye, was opened. These schools, however, did not comprise a unit similar to a university, but later conglomerated to make the first university-like establishment, Darulfunun, in 1863. During the reign of Mahmut II, children of the high ranking bureaucrats in the Ottoman Court and its branches were encouraged to go to these new schools. In 1820, the Besiktas Society of Science was established by some of the high ranking bureaucrats who held their meetings at their houses. This can be viewed as the first faculty organization in Turkish higher education (Gunal and Gunal 2011). Later these people were exiled and accused of being Bektashi, a non-mainstream, Alevi Islamic sect, in the state's attempt to prevent the growth of this scientific organization (Tekeli and Ilkin 1993).

The first elementary level schools (Sibyan Mektepleri) were opened in 1824 and elementary education was mandated for Muslim children by an imperial edict; but schooling rates still remained low. In 1838, public middle schools (Rustiye Mektepleri) were opened, but their dispersion across the empire had been quite slow (Tekeli and Ilkin 1993). In 1845, concerned by the slow progress of public education, Sultan Addulhamid II proposed that the focus should be on how religion and reason can be reconciled (Berkes 2002). In the same year, new military schools at the middle school and high school levels were opened. To provide the work force needed for these newly opened schools, a Normal School for Boys (Darulmuallimin 1847), a middle-school level teacher-preparation school (Darul Muallimi Sibyan 1862) and a Normal School for Girls (Darulmuallimat 1870) were opened. Two of the biggest successes of this era were the inclusion of girls in middle education, and the sending of graduates of the engineering school to Europe between 1846 and 1855.

In 1841, Prof. Bernard, who was invited from Vienna and served as palace physician, secured permission from the Ulema to work with human cadavers which was previously prohibited (Yildirim 2014). The Medical school, which had a 9 year program that heavily emphasized science content within the first 4 years, saw its first graduates in 1843. Scottish author Charles MacFarlane noted interesting observations about the Ottoman medical school. According to MacFarlane's notes, Turkish medical students read books about materialism and appreciated these views. *Systeme de Nature* by Baron d'Holbach and writings of Diderot and Cabanis were some of the work MacFarlane referred to. MacFarlane was surprised when he learned that Voltaire's *Dictionary of Philosophy* and *Candide* were translated into Ottoman. Berkes (2002) noted that these observations were shocking for MacFarlane, who had anti-materialist views. Berkes adds that the Medical school raised important intellectuals including Hayrullah Efendi, Hekim Ismail Pasha and Fuat Pasha.

In 1851, Cevdet Pasha founded Encumen-i Danis, a type of scientific society whose purpose was to provide a venue for intellectual discussions, encouraging scientific research, and illuminating the public about scientific advancements. The idea of Darulfunun was first seeded here (Berkes 2002). Later, some who had left Encumen-i Danis founded another scientific society, Cemiyet-I Ilmiye-I Osmaniye. From this latter group, Tahir Munif Efendi published the first science journal, *Mecmuai Funun* in 1862. Later, two public high schools (Sultani) were opened, Galatasaray (1867) and Darussafaka (1873). It is interesting to note that the first modern university type establishment, Darulfunun (1863), opened before these high schools. Darulfunun would have initially suffered from a lack of students; these feeder schools would partially offset that problem.

The Engineering schools that were opened in the eighteenth century provided the foundation for Darulfunun, which literally means science-house. It was intentionally named so that they were distinct from madrasas which were educational institutions that primarily taught religious studies (Gunal 2013). In 1863, some scientific demonstrations and experiments were made open to the public and garnered much attention. In one of these events, Dervish Pasha demonstrated electricity. Soon thereafter, the Ottoman Government opposed these science demonstrations for two reasons. First, it was thought that these demonstrations and experiments were against religion. Relatedly, a second reason was that some thought that it was inappropriate for high ranking government officials to take part in them. Darulfunun was closed two and a half years after its opening due to a fire; it reopened and closed several more times thereafter. As Gunal (2013) emphasized in his book, it was understood at that time that elementary and secondary education should also have science content in order to provide students for Darulfunun.

But, this begs the question as to why Darulfunun opened first, in the absence of a supporting public education system. The answer is twofold. First, some of the Ulema within the madrasas resisted modernization. The Ulema wanted to protect their privileged status in the theocratic society. Second, the leaders of the Ottoman Government perhaps sought a quick remedy for the economic loss and weakened government authority by simply hoping that Darulfunun would improve the deteriorating conditions. It was easier to provide a higher education for a small, young, elite group in Istanbul than making a grassroots movement of public education across the country.

In 1864, a new unit in the Ministry of Education was established (Meclis-i Kebir) which included one appointed representative from Greek, Armenian, Catholic, Protestant, and Jewish communities. In 1867, France gave a diplomatic note to the Ottoman Government for reforming the education system that influenced the passing of the Ordinance of General Education in 1889.The 198-item ordinance addressed teacher education, reserving the existing Christian schools and opening new ones, establishing mixed-sex education, and opening new public libraries (Altin 2008). In addition, it addressed the opening of elementary schools (Sibyan mektepleri) in every village, middle schools (Rustiye mektepleri) in each town, high school preparation schools (Idadi) in larger towns, and high schools (Sultaniye) in each regional centre; and teacher colleges for men and women in Istanbul and a new university were proposed.

After the Ordinance of General Education came into existence, Darulfunun was reopened in 1870 with a new name, Darulfunun-u Osmani. It included faculties of Law, Literature, and Science. The opening ceremony was made in three languages. Tahsin Efendi, the first director of Darulfunun-u Osmani, spoke in Turkish, Greek instructor Jan Aristokles spoke in French, and Cemalettin Afgani spoke in Arabic. Tahsin Efendi, who was educated in France, influenced many Darulfunun-u Osmani students who were taught in the French language. Many resource books and journals were ordered from Europe. Even though Tahsin Efendi went to Medrese and received a religious education, he was accused of blasphemy and eventually dismissed. Similarly, Cemalettin Afgani Efendi, another leading figure in the school, was accused of atheism upon his remarking that prophecy is an art. He had to eventually leave Istanbul (Tekeli and Ilkin 1993; Berkes 2002).

In 1872, Darulfunun was closed for the second time. Although at the surface level the reason for the closing was Cemalettin Afgani's actions and remarks, it was clear that Sheikh al-Islam, the religious authority, did not like Darulfunun. In addition, the facts that Tahsin Efendi had endorsed the then-current French education system, that he was a Bektashi, and that Darulfunun housed several other progressive educators made Darulfunun an easy target for accusations that led to its closing. Perhaps the naming of Darulfunun (which literally translates to science house) instead of disguising it with a different name such as darululum (house of knowledge) was a strategic mistake (Tekeli and Ilkin 1993).

Because of the attacks from reactionaries and lack of legislation protecting Darulfunun, its third opening, which occurred with little fanfare in 1874 was under the name of Galatasaray Sultani. This third iteration of Darulfunun was the first to produce graduates, all of whom were taught in French because of a lack of instructors who could teach in Turkish (despite the official language of the school being Turkish). The Galatasaray Sultani was closed in 1877 due to what is generally believed to be economic problems and the Ottoman-Russia wars. However, Gunal (2013) suggested another possibility for the closing of the Galatasaray Sultani. At that time, the Ottoman Empire lost its power within the Balkan region. Because most of the Galatasaray Sultani's students had Balkanian origins, the closing of the institution could have been a political move to prevent the education of Balkanian youth which the government feared could betray the Empire.

In 1896, the Grand Vizier Said Pasha submitted a report to the Sultan Abdulhamid II indicating that the Ottoman Empire could only be successful in competing with the West if the Ottoman people widely endorsed a scientific worldview. In 1900, Darulfunun reopened for the fourth time with five faculties including an education faculty. During the reign of Sultan Abdulhamid, there was a great level of censorship by the ministry of education of what was taught in Darulfunun, especially in the social sciences, because of a fear that education could lead to changes society and a reduction in the Sultanate's power. Hashem Pasha, the Minister of Education, accused Darulfunun of eroding the moral values of its students.

With the second constitutional era beginning in 1908, Emrullah Efendi became the Minister of Education who advocated for a compulsory, free elementary education (Gunal 2013). At the time, it was believed that the quality of primary and secondary education would increase with a rise in the rate of higher education attainment. Thus, there was an increased interest in the opening of new institutions of higher education. In 1912, the name of Darulfunun was changed to Istanbul Darulfunun. Later, during WW I, Allied forces occupied Istanbul and many faculty members who were thought to be members of the Ittihat and Terakki (Committee of Union and Progress), a Turkish nationalist group, were exiled. Some of the remaining faculty were discharged. Despite all these pressures and the devastating effects of the wars, Istanbul Darulfunun remained open until 1933 (Gunal 2013).

Darulfunun was also a milestone for co-educational education. In 1914, the first female students were accepted although they were taught in separate classrooms from male students. However, because of a negative societal reaction to this, Inas Darulfunun with teacher education programs in literature, mathematics, and natural sciences was opened exclusively for women. In 1921, Mustafa Kemal Ataturk opposed single sex education during the National Education Congress, bringing about some mixed-gender classrooms. Still, some women boycotted these classes.

In the meantime, Ionia University, the first institution to carry the word "university" within its name, was established in 1919 by the Greeks in Izmir (Gunal 2013). Its founder was Konstantionos Karatheodoris, a well-known mathematician who also taught Albert Einstein. When the Greek invasion of Western Turkey was halted during the Turkish Independence War, the Greeks reduced resources for this university.

The trajectory of the Enlightenment tradition within the Ottoman society had its ups and downs. While efforts were made to move the society forward through education, these efforts periodically fell short as evidenced by Darulfunun's history. Perhaps the biggest barriers for change were the primarily agrarian society with its traditional values, and the existing medieval structures, including the still influential Ulema class. In addition, in response to weakening economic conditions due to land lost and diminishing tax revenues, religious and nationalistic conservatism emerged which further increased society's resistance to change.

3.5 First Half of Twentieth Century: A New State

The 1920s were marked by a post WWI economic depression, continuing wars for independence, and the foundation of the new Republic of Turkey. Before the Turkish Republic was founded in 1923, the Sultanate was abolished in 1922. Later, in 1924 the Caliphate was abolished and a special law (Tevhid-i Tedrisat) regulating the unity of all instructional practices was passed. This meant the closing of institutions that solely taught Islamic doctrine, such as Madrasas, and the opening of secular institutions (Okcabol 2005). In the meantime, another education law regulated how religious education was to be given. In 1924, Prayer Leaders and Preachers schools (Imam Hatip Schools) were opened, followed by theological schools. Although it may seem counter intuitive that a secular government would open imam schools, they did so to create a new clergy class who was well-educated and practiced a non-extremist form of Islam. In 1928, coeducational institutions were established and the Latin alphabet was accepted. Natural sciences, physics, and chemistry became mandatory courses. Further, all of the educational services were now controlled under the authority of the Ministry of Education. All of these changes were quick and revolutionary.

For the first time, secularism in Turkey found its constitutional recognition and legitimation when in 1928 when the article declaring Islam as the official state religion was removed from the constitution. Later, in 1937, secularism was added to the constitution as the defining feature of the state (Berkes 1998). The Turkish idea of secularism was borrowed from the French laicism and appropriated in a unique way. That is, secularism should not be understood as an abstract concept and legal bundle of rights and policies. Rather it should be understood as a specific ideology, bound to a particular religion and political context (Cinar et al. 2012).

In the case of Turkey, secularism is not just a mechanism for the government to control the religious practices, but, more importantly, it is a way to use religion as means to establish state authority. Unlike some Western states such as France, the church and state in Turkey has never been separated. The Department of the Affairs of Piety (Diyanet) continues to be a state branch, organized directly under the office of the prime minister. As such, using public funds, it manages various religious affairs such as, appointing imams and muftus, maintaining mosques, distributing religious publications, etc. One example of how the state controls religion in public spaces was the banning of head scarfs in schools, universities, and government offices for many years, until this ban was abolished under a more recent regulation. Diyanet issues a Friday hutbe (sermon script) every week and this is read to the Muslim followers in approximately 85,000 mosques across the county. These hutbes mostly address the original and central ideas of Islam, but they are often coloured with the official ideology of the state.

Ataturk's Turkey (1923–1938) faced toward the West, and it had a firm positivist authoritarian ideology driving it to get rid of some of the old structures that seemed to be obstacles for change. From the epistemological stand point this ideology assumes that what we know about nature and society is the same kind of knowledge, and from the political standpoint this knowledge has the function to shape and control the society (Toker and Tekin 2007).

The roots of positivism in the Turkish Enlightenment tradition go back to the Tanzimat period. First, several Ottoman ambassadors in France were directly exposed to positivism. For example, Mustafa Resit Pasha (1800–1858) read August Comte, and under Resit Pasha's auspices, Ibrahim Sinasi (an author and journalist) became friends with such French philosophers as Earnest Renan and Emile Littre. This trend continued over several decades and a growing number of Turkish intellectuals subscribed to positivist thought and became influential thinkers of the time including Riza Tevfik, (1868–1949), Huseyin Cahit Yalcin (1874–1957), and Ziya Gokalp (1876–1924), (See Korlaelci 2009).

History and literature were the fields where the first gleanings of positivist thought were seen in Turkish intellectual culture. Beginning from the Tanzimat period to the early years of the Turkish Republic until the death of Ataturk, the history textbooks' descriptions of the early historical ages removed religious accounts of the origin of humans, and adopted a naturalist approach supported by physical anthropological evidence. In these textbooks, it is stated that "God" is an imagination of the human mind rather than the creator of everything. The "chain of life" claim that humans originated from other life forms was embraced by history textbooks (Toprak 2011). Beginning in 1930, mandatory religious courses were gradually removed and religious expressions were removed from general education programs and textbooks (Eskicumali 2003). The curriculum was related to daily life and secularized. For the first time, in 1934, the theory of evolution appeared in the nation's curriculum. Many foreign textbooks and resources were translated into Turkish. In 1934 the constitution was changed so that women were given the right to vote and to be elected to parliament. Thus there were a number of major radical social, cultural and educational changes that all occurred within a decade.

By 1924 news spread that the alphabet would be changed from Arabic to Latin. Darulfunun faculty indicated that they would boycott this. For the new republican regime to flourish, restructuring of the Darulfunun was necessary (Gunal 2013). Beginning in 1928, supported by a new legislation, students were sent abroad for advanced academic studies to provide the academic workforce needed to restructure Turkey's system of higher education. An amended version of this law is still in effect resulting in many modern faculty members in Turkey who obtained their terminal degrees from abroad. About this same time, the Ministry of Education requested a report from Swiss-German educator, Albert Malche, regarding the status of Turkey's higher education system. The resulting report indicated that Darulfunun did not contribute to Turkey's knowledge base; simple translations from Western work were admitted as dissertations; faculty, who were often occupied with outside jobs, had minimal involvement in the campus; and advisement, mentoring, and scholarly work were absent. Turkish reporters made similar observations as well and the government decided to take action (Oncu 2007).

In 1933, Darulfunun was closed for one day and the name was changed to Istanbul University. One hundred and fifty seven of the 240 faculty members were discharged and provided the option of working for another department within the state. This represents the first ideological retrenchment of university faculty within Turkey and was part of a larger effort to establish a modern university. It strove to fortify the single party regime's higher education ideology of strengthening the secular nation-state model while continuing to modernize. Interestingly, Oncu (2007) points out that this reform was paradoxical in and of itself, as the relatively self-autonomous Darulfunun was replaced with an institution representing the authoritarianism of the government.

Faculty positions at the new Istanbul University were filled with the remaining Darulfunun academics, young academics who were returning from their training in

Europe and many scientists who escaped from Nazi Germany (Gunal 2013). It is worth noting that the quality of faculty who left Germany and came to Istanbul University were among the best in their disciplines. Alfred Kantorowicz was an eminent dentist, who remarked that Istanbul University was the best German University of the world. These German academics were political dissidents in Nazi Germany; they were liberals who were primarily socialists and Jewish (Guleryuz 2008; Oncu 2007). In 1933, the Advanced Agriculture Institute was opened in Ankara with Friedrich Falke serving as its first rector. Although it was classified as an institute, in several respects it was thought to embody more university characteristics than Istanbul University itself (Gunal 2013). In fact, Turkey's first doctoral program was opened in this highly research-orientated institution. This institute later became Ankara University in 1946, with strong programs in the natural sciences.

In order to re-structure schooling and establish a public education system, Turkey invited several educators and academics to consult in the planning of these reforms and new initiatives. The most influential of these people was John Dewey who made his first visit during the summer of 1924. During a three-month visit he visited schools in Turkey and spoke with teachers, school administrators, and higher level officials. Upon leaving, he created an initial report followed up by a more comprehensive report on the Turkish education system that addressed aspects of instructional programs, the Ministry of Education's organization, teacher education, the schooling system, health and hygiene, and school discipline. Through these works, Dewey discussed the problems of teachers and teacher education, the importance of translating basic science education resources to Turkish, and the democratic administration of schools (Dewey 1924a). Ultimately, Dewey provided several recommendations related to the decentralization of education, the re-structuring of rural education based on local needs, the opening of local and mobile libraries, and establishing educational unity while avoiding uniformity.

The influence of Dewey on the Turkish education system was contentious for several reasons. First, Dewey and Turkish leaders philosophically differed on the purpose of education. For Ataturk and his officials, education was a political tool to help shape society as the new state sought to develop its identity. For Dewey, however, education was rather a social ideal that contributed to the ongoing free growth of society (Santoro and Dorn 2012).

More importantly, Dewey and Turkish officials also differed on the administration of education; while Dewey advocated a system with strong localism, Turkish officials believed in a centralized education system which imposed a national curriculum. Even though Dewey acknowledged that the central government should lead the reform movements, he warned that a highly centralized education system would make the social ideal of democracy impossible, due to a lack of local community involvement. Along this vein, Dewey warned that a high level of nationalism and centralism would result in anti-democratic practices (Santoro and Dorn 2012). This is exactly how Kemalism (i.e., the principles of Ataturk) is criticized by many modern intellectuals, who assert that it suppressed different ethnic and religious identities.

However, Ataturk's prime goal was to build a nation and a secular government. Over the previous two centuries, the Ottomans failed to save the state while attempting reforms. The Empire was dissolved with most of the Balkan nations claiming their own sovereignty and Arabic nations becoming colonies of the Western States. Ataturk recognized that the Turks were predominantly poor, uneducated peasants who did not have a strong sense of Turkish identity because the Ottoman Government treated them according to their religious affiliation. Ataturk believed that for the new state to survive and flourish it must be based on a strong Turkish identity. As Bilgi and Ozsoy (2005) pointed out, for the new Turkish Republic's ruling elite the main causes of the predicament were traditional and religious values of the people. Thus, Dewey's recommendations on local community involvement were not considered. A national secular education system and curriculum would ensure that the state's political goals will be better achieved.

Santoro and Dorn (2012) discuss other accounts of Dewey's work that represent contrasting claims about whether Dewey's recommendations were actually implemented. For instance, Joseph Szyliowicz regarded the influence of Dewey as being very little to none. Yet, according to Ata (2000), Dewey's report significantly influenced the Turkish education system. Ata suggests that some of Dewey's influences include the opening of the Department of Instruction and Education (Talim ve Terbiye Dairesi), the Gazi Teacher Training Institute, and the Bureau of School Architecture. In addition, the Ministry of Education's academic journals, such as *Maarif Vekaleti Mecmuasi*, often published articles on the education systems of other countries including, among others, France, Germany, Italy, Russia, and Japan. This is consistent with Dewey's suggestion that Turkey should synthesize its own education system by adopting elements from various other systems instead of completely copying another nation's entire system. Furthermore, library networks were developed and mobile libraries were established to reach out to the people in remote places so that the ideals of the new republic could be disseminated (Ata 2000).

Dewey wrote four essays on Turkey after he returned to the USA. In "Secularizing a Theocracy", Dewey (1924b) notes that the young Turkish republic was destined to be a secular state. Dewey reasoned that this was inevitable because most Western nation states followed the same model. Additionally, he cited the treacherous dealings of the Sultanate with foreign powers, as well as the degeneration of the Caliphate institution as important contextual elements that ultimately supported the secularization process. In "Angora, The New" (1924c) Dewey shares his reflections about Turkey's new capital, Angora (Ankara), and discusses the reasons for the new state's choice of Angora over Constantinople as her capital. In "The Turkish Tragedy", Dewey (1924d) discusses the underlying events that caused the civil wars that alternately pitted the Turks against the Greeks and the Armenians. Dewey attributes some of the blame for these wars and their resulting tragedies to the "Great Powers" of the time, Russia and Great Britain, who provoked ethnic clashes among Ottoman nations. Finally, in "Foreign Schools in Turkey," Dewey (1925) provides a glimpse into Turkey's foreign schools and discusses the perplexity of keeping foreign schools open during the beginning years of the Turkish Republic in an era of elevated nationalism.

One of the most significant products of the Turkish enlightenment movement were Village Institutes that addressed some of Dewey's recommendations about rural development. The founders of the Village Institutes were the Minister of National Education, Hasan Ali Yucel, and the Elementary Education General Manager, Ismail Hakki Tonguc, both of whom were important figures in the nation's education history. The Village Institutes were coeducational institutions established in rural areas with the goal of rural development and creating teachers to be placed in rural elementary schools. It is also argued that these institutions were founded to instil the ideology of the single party regime in the rural areas (Karaomerlioglu 2009). American educator Fay Kirby (2000) noted that the Village Institutes were not a copy of the Western institutions and had been very influential in educating rural people.

The first Village Institutes were opened in 1940 and lasted until 1947. The opening of Village Institutes caused outrage among the right-wing politicians within the Parliament. By 1945, it was recognized that the Village Institutes had revolutionized rural education (Arayici 1999) and were producing approximately 2000 graduates each year. Thus, it is worthwhile to look at the operation of these schools more closely by first examining their guiding principles benefiting the rural community including, a) field-based rural education, b) learning by doing, c) connecting agricultural production with science and technology knowledge, d) providing health and hygiene for rural populations, and e) bringing cultural activities from the larger cities and Western culture. The Village Institutes were designed to be self-sustaining and rejected the standard rote learning approach. Observation, experimentation, research, and discussion were some of the strategies used in these institutions (Oguzkan 1990). The goal of the Village Institutes was to raise enlightened, productive, sociable, and educated citizens.

In some respects, the Village Institutes addressed several of the issues in Dewey's report including a pragmatic approach to education with many opportunities to practice and apply skills, a consideration of local needs, and a focus on rural education. In one anecdote, Hasan Ali Yucel told the president of the Turkish Republic that the Village Institutes were created with Dewey's ideas in mind (Inonu 1998). After WW II, Turkey transitioned to a multi-party political system and became more politically aligned to the USA. During this period, Hasan Ali Yucel was not elected to Parliament and Hakki Tonguc, and their working team, were eliminated. Resat Semsettin Sirer, who was known to be a Hitler admirer, became the next Minister of National Education (Ak 2015). Sirer believed that those who were educated in the Village Institutes were communists and would 1 day rise up against those in power. Additionally, the Village Institutes were under political attack from the conservatives because a coeducational boarding school concept was hard to accept and, as was very typical for the period, they were accused by right-wing politicians of creating communist propaganda (Gunal 2013).

In 1946, similar accusations regarding communism became widespread in other universities, leading to the dismissal of several leading academics, including Niyazi Berkes, Pertev Naili Boratav, and Behice Boran (Oncu 2007). The founder party of the republic, the Republican People's Party (RPP), was becoming more conservative and eventually the right-wing Democrat Party (DP) separated from RPP. The depression years during WW II were characterized by an increase in religious conservatism. In 1950, the DP won the elections as the first party to be elected in a multi-party election. The conservative Minister of National Education, Tevfik Ileri, first separated the co-ed Village Institutes into two single-sex institutes for boys and girls. Further, he invited K.V. Wofford, an obscure figure from Florida State University, to prepare a bogus report that would provide a basis for the closing of all twenty Village Institutes (Altunya 1999).

Karaomerlioglu (2009) provides an interesting perspective regarding the reasons for the closing of the Village Institutes. First, these institutes went beyond their initial mission of establishing a sustainable village life where villagers learned to increase agricultural productivity. Instead, educated village men began to migrate to the cities. Second, these institutes were very much associated with the single party regime and were seen as an obstacle to the transition to a multi-party system. Thus, contrary to the popular belief that the RPP opposed the closing of these schools, the RPP leadership actually supported their closing for political purposes. The RPP's right-wing leaders wanted to weaken the opposition while gaining the favour of Western allies by accusing the Village Institutes of spreading communism. Today, the Village Institutes still remain an interesting enigma of Turkish political history.

In 1946, "Universities Laws" that reformed the way universities operated passed. According to new laws, universities were provided with more autonomy and legal personality in response to increasing demands for higher education. Universities were provided with a self-governance model, this was an improvement over the 1933's authoritarian reform that abolished Darulfunun (Korkut 2003; Oncu 2007).

In 1948, religion courses were included in the national curriculum as electives. Later, the DP kept their promise to re-open imam schools and by, 1951, every student was required to take religious courses unless they overtly declared an unwillingness not to do so, which, because of social pressures, was not easy to do.

Subsequent to WWII and Turkey's admission into the United Nations and NATO, Maarif Colleges (secondary level schools) were opened. In these schools the medium of instruction was English for mathematics and science courses. During this period Turkish Education, formerly influenced by continental Europe, was increasingly influenced by American education views (Akyuz 1999). It was during this time (1951), when the Cold War began, that right-wing political leaders re-opened Prayer Leaders and Preacher Schools to counterbalance leftist political currents.

While Sputnik affected science education within the U.S., the Turkish system was also affected in specific ways. For example while atomic theory and the theory of evolution were introduced in textbooks plate tectonic theory was not. (Tebligler Dergisi 1957). The overall quality of the curriculum was improved while conservative ideologies gained greater prominence (Durmus 2013). During this time, a Turkish McCarthyism prevailed in which there was widespread right-wing political discourse regarding how to defend against communism and materialist ideology that ignored society's values. Also at this time, Middle East Technical University (METU), a very influential Turkish University, was established (1956) with U.S. support. Ironically, even though METU was opened by a right-wing Turkish administration and received U.S. support, the students of METU were mostly known to be much more sympathetic to leftist ideals and were very influential during the student demonstrations following 1960 (Caliskan 2015).

3.6 Military Coups: 1960–1980

In the two decades after 1960, Turkey experienced three military coups. The first of these occurred in 1960 as a result of the Democratic Party administration's extreme authoritarianism and conflicting policies toward the secular model of governance (Howard 2001). The military intervention resulted in the removal of the Democratic Party from power, execution of the Prime Minister and two cabinet members, and, later, the passing of a new constitution. The junta regime declared its allegiance to NATO and other international organizations. As in continental Europe's post-war era, a planned economy model was adopted and the State Planning Organization was established. Even though it was passed during a junta regime, the 1961 constitution was regarded as being very liberal because it allowed for the existence of labour unions, provided a higher level freedom of expression, supported a more autonomous structure for universities, and introduced the notions of "social government" and "pluralistic democracy" (Birol 2012). In the 1965 elections the Workers Party of Turkey won seats in the Parliament, a first for a socialist party. In 1967, the Confederation of Progressive Trade Unions (DISK) was founded.

Following creation of the 1961 constitution, new economic planning and development packages were proposed that targeted a basic education for everyone as well as increased vocational and technical schools to produce qualified technicians and scientists (Okcabol 2005). The first science magnet high schools (Science Lycees or Fen Liseleri) were established in the early 1960s and Ankara Fen Lycee received support from the Ford Foundation. Taken together, these efforts were aimed at raising a new generation who were better versed at questioning, reasoning and inventing (Yılmaz and Morgil 1992).

During this time, the influence of positivism can be seen within many new education programs. For example, some of the science magnet lycees' curricula were adopted from America. In 1962, 20 science and math textbooks and curricular programs were translated into Turkish by the Science Textbooks Translation Project. The Physics Sciences Study Curriculum (PSSC), Chemical Education Materials Study (CHEM Study), and Biological Science Curriculum Study (BSCS) programs were adopted in physics, chemistry and biology courses. With these new curricular programs, textbooks included terms such as 'theory', 'observation', and 'hypothesis', as well as discussions about the nature of science (i.e., methods of science, the role of scientists, and the definition of science). In 1963, The Scientific and Technological Research Council of Turkey (TUBITAK) was founded to support research and development projects at Turkish institutions, provide scholarships for researchers, and publish popular science magazines and books for that were very affordable priced for the public.

Reform strategies of the 1970s stressed the protection of youth from extremist ideologies. However, the cold war era of street demonstrations and clashes between opposing youth groups was a harbinger of future military take-overs. The 1971 coup resulted in the closing of both the Workers Party of Turkey and the Confederation of Progressive Trade Unions. During this period, while all vocational middle schools were closed, imam schools at the middle grades were re-opened (Okcabol 2005). Coeducational imam schools were opened at the high school level, even though females could not serve as imams in Islam (Altunya 1999). Because of a fear of communism, educational policies aligned with right-wing conservatism as well as nationalist and Islamist values.

3.7 Towards a Market Economy: 1980–2010

This period was characterized by the 1980 military coup, a new constitution (1982), a transition to a free-market economy, legislation creating a new Higher Education Council (1983), the establishment of non-public foundation universities, and the depoliticisation of universities. As Turkey approached the 1980s, the bourgeoisie class grew and it was evident that they needed to integrate to the rest of the world economy. However, Turkey did not have a true free market economy, as the government heavily regulated most areas of economic production.

In May of 1979, the Turkish Industry and Business Association's (TUSIAD) full page newspaper ads called for a change in Turkish economics. These ads were so influential during a time of political instability that they triggered the overthrowing of the social democrat administration of the time. On January 24, 1980, new economic regulations were released by the government that abolished the mixed economic system involving heavy government regulation of private investments and capitals; a free market economy model was adopted. Later, on September 12, 1980, the military once again took control during a time of political and economic instability, where political assassinations and street clashes were increasingly common.

The junta regime was an effective apparatus for implementing this new economic model while easily suppressing any opposition. The mastermind of January 24 decisions, Turgut Ozal, was later elected as the Prime Minister in the first general elections in 1983 after junta regime ostensibly relinquished power. During these elections the most significant political actors were banned from politics, paving the way for an easy win for Ozal, who also received international support from such leaders as Reagan and Thatcher.

It would be foolhardy to think the 1980s coup and its aftermath were independent from global politics. For instance, the U.S.'s support of radical political Islam during the Cold War era in response to Soviet Union threats is well documented (Dreyfuss 2005). Turkey's politics was also influenced by this increasing level of political Islamism. During Ozal's term, religion classes became mandatory in all middle and high school grades. Biology textbooks of the national curriculum had ideas suggesting that the theory of evolution was questionable (Durmus 2013). A book entitled *Creationism* and published by the Institute for Creation Research (ICR) in the U.S. was translated into Turkish by the Ministry of Education Press and sent out to all biology teachers (Edis 1999). The Minister of National Education of at that time, Vehbi Dincerler, accused those teachers who taught the theory of evolution of being communists (Sayın and Kence 1999).

In a report by the State Planning Organization (Devlet Planlama Teskilati or DPT), it was recommended that all curricular content should be in harmony with religion (DPT 1983). Creationist ideas were also added to the biology textbooks of the national curricula as an alternative hypothesis to explain the origin of life (Sayın and Kence 1999). Even though the theory of evolution remained in the textbooks, it was largely diluted with creationist references. At the same time, religion course textbooks attacked the theory with misconstrued interpretations. For instance, one reads "according to Darwin, strong ones would live, and weak ones would be eliminated. However strong organisms such as dinosaurs and mammoths have become extinct, whereas some weak organisms such as earthworms could survive" (Ayas and Tümer 1994, p. 13).

The coalition administration of 1996 passed a bill to change the duration of mandatory education from 5 to 8 years. The key to the bill was that during this mandatory 8 years of education, no vocational or Prayer Leaders and Preachers Schools were offered at the middle grades level (grades 6–8). Previously, students could choose to go to these sorts of schools, beginning at the sixth grade and continuing to high school in the same area. Prayer Leaders and Preachers Schools were very important in politics as evidenced by one of the political leaders confessing "Imam schools are our backyard" thus suggesting that graduates of Prayer Leaders and Preachers Schools were avid supporters of his political movement.

The higher education situation was no different. The 1980 junta regime established the Higher Education Council (Yuksek Ogretim Kurumu or, YOK) in 1981 that oversaw all of the state's higher education institutions - there were not any private higher education institution at that time. One of the first moves by the Higher Education Council was to discharge hundreds of faculty members who were mostly social progressivists and leftists. YOK legislation equipped the university presidents (rectors) and deans with unprecedented authority so that they could control the academia in the interest of the ruling administration (Oncu 2007).

Although most members of the Higher Education Council are academicians, they are appointed by the President, and therefore, the council is very political. As such it acts as if it is a branch of the ruling administration. For instance, in 1986 during the aftermath of the Chernobyl disaster, several Turkish scientists did investigations about the increased radiation amounts in the black sea region of Turkey. The Higher Education Council prevented these scientists from disseminating their results. Most recently, the Higher Education Council communicated to the universities in a confidential note that academic research on Syrian refugees in Turkey was not allowed without first receiving the permission of government authorities (Odatv 2015).

During the subsequent 2000s, concepts such as individualism and entrepreneurism become more prevalent, and the influence of globalism and neo-liberal discourses has become more visible. Constructivism became a preferred educational theory, along with eclecticism. On the other, this did not mean that government or political authority embraced pluralism; dissidents, including college students, continued to suffer from the laws inherited from the last junta regime. Any divergent political idea can be interpreted as a threat to the "indivisible integrity of the state" according to the Turkish Penal Code, resulting in jail time.

In this period, constructivism and post-modernist discourses gained more popularity in Schools of Education, teacher education, and school curricula. In the 1980s and 1990s, huge numbers of Turkish students were sponsored by the State to pursue graduate studies in the UK and USA. In both countries, constructivism was in its ascendency. Not surprisingly, this doctrine was brought back to Turkey. Commonly Schools of Education taught that each individual learns differently, there are multiple ways to reach the truth, there is not an absolute truth, and knowledge is constructed and culturally bound and grounded. With little intellectual debate, constructivism was endorsed as the guiding philosophy of science curricula (MEB, Ilkogretim Fen ve Teknoloji Dersi Mufredati 2006). The American National Science Education Standards (NSES, NRC 1996) has been influential in shaping the science curricula at grades 6–8. Similarly, the high school biology curriculum has been influenced by the Campbell biology curriculum. However, interestingly, sections relating to the theory of evolution were excluded from the Turkish Biology textbooks. In the meantime, creationist propaganda peaked, partly through the support of the state, as public schools allowed the distribution of free creationist publications(including the notorious *Atlas of Creation*) and field trips to so called fossil museums funded by creationists. Although a critique of the science curriculum has been made (Taskin 2005), along with several critiques of how evolution is presented, (Peker et al. 2010; Taskin 2011, 2013), these have had little influence on what is implemented within the schools.

Also, during this period values education became part of the curriculum, especially within the early grades, along with a great deal of research being conducted on values education in Turkey. Although values are important elements of human development and identity, it appears that the values education, as practiced, promotes primarily those values associated with religion rather than more universal or secular values. Unfortunately, it has been shown that prospective teachers' religious values negatively affects their attitude toward science (Mugaloglu and Bayram 2009).

In 2012, public education at the primary and secondary level was structured with a 4 + 4 + 4 model, in which students take 4 years of primary education, followed by another 4 years of education at the middle grades level, and then 4 years of secondary education. The key to the model is that for the second four-year term, students can choose the option of going to vocational schools, one of which is the Prayer Leaders and Preachers Schools (Imam Hatip Okullari). The middle grades sections of these schools were closed in 1997, and it is the current Justice and Development Party administration's agenda to increase enrolment in Imam Schools, something that has been very controversial since these schools' first inception in 1951.

One of the critiques of the 4 + 4 + 4 model is that it primarily serves the needs of the market economy rather than the developmental needs of the students. In this model, primary education starts at age five, with the second four-year period beginning at age nine, when students can enrol in vocational schools. Although current laws prohibit businesses from hiring anyone younger than 15 years old, a specific rule was added that allows businesses to hire children younger than 15 years old who are enrolled in a vocational school (Muftuoglu 2012). Clearly these new policies serve a neo-liberalism philosophy in which schools are evaluated based on their ability to produce a workforce that is economically productive rather than their ability to create liberally educated citizens (Inal et al. 2014).

At almost all levels, the Turkish education system uses high stakes tests to determine which students will be eligible to go the next level of specialized (magnet) schools or college. During the last 13 years, the testing system has been changed five times. Entry into secondary education (Grades 9–12) has been very confusing for most parents and students with the different categories of schools' names repeatedly changing. Also, many regular high schools have been converted to Prayer Leaders and Preacher schools. For instance while the number of these imam schools was 450 in 2003, their number has increased to 1000 by 2015, with almost half a million students enrolled (Anadolu Agency 2015). When mandatory religious courses are required at the expense of science courses in public schools, and public religious schools are promoted at the expense of non-religious schools, Turkey's success in the core areas of education is diminished. For instance, in the Programme for International Student Assessment (PISA) study of 2012, Turkey was ranked at the 44th place among 65 OECD countries in mathematics, science and reading achievement (OECD 2014).

The Turkish higher education system has grown very fast in the last decade. The number of universities almost doubled from about a 100 at the beginning of the 2000s to 193 as of 2016. However, the number of higher education institutions in Turkey is still much fewer than some of the other countries of comparable size in the West. The quality of higher education has been questionable as most new institutions lack the physical, academic, and personnel infrastructure to support quality education. Furthermore, the entire higher education system needs a major overhaul because it is managed by the central Higher Education Council, a very highly political institution with its members and president appointed by the President of the country. This system threatens academic freedom and tenure as individual faculty members can be easily penalized by the central authority as well as their local university administrations because of their dissident ideas (Ugur 2016; Bohannon 2016).

3.8 Conclusion

From the beginning reform movements of the eighteenth century Ottoman Empire to today's Turkey, all had an elitist character (Berkes 2002; Gulalp 2005; Weiker 1981). The ruling bureaucracy assessed the need for reforms and implemented them accordingly, with mixed success. However, the Turkish reforms during the period between 1923 and 1946 have been revolutionary and progressive in the sense of dismantling old structures. Even though Turkey moved to a multi-party democratic system in 1946, this was the beginning of a counter-revolutionary period as the gains of republican revolution were sacrificed for the political zeal of the ruling parties. Perhaps the most significant example of this was the banning of the Turkish call for prayer from the mosques and reverting back to the Arabic call, a language that the overwhelming majority of the people did not speak. This was such a quintessential problem. If enlightenment is simply putting reason before anything else, how could one put reason before something (i.e., a religion) that one cannot even understand because of a language barrier? Another turning point was the closing of the Village Institutes which ultimately made it difficult to modernize because there was no longer an organized way to reach out to the rural communities.

The years between 1946 and 1960 were a period of growing conservatism fuelled by the cold war. The period between 1960 and 1980 has been relatively more liberal, with some interruptions due to military interventions and tensions between opposing groups. This period also represents the growth of the much more positivistic science education curricula. Beginning with the aftermath of the 1980 coup, authoritarianism and conservatism climbed. The 1980 military coup and the resulting 1982 constitution passed by the junta regime tremendously impacted Turkish education, politics, and social life.

This 1982 constitution, with many amendments, is still in effect in modern Turkey. Originally, it limited freedom of expression and social pluralism to a great extent. Starting in the mid-1980s, the armed Kurdish movement arose and by the 1990s praetorianism became the modus operandi; increased ethnic tensions primarily fed nationalism and Islamism while leftist elements were greatly suppressed. The ensuing years of the 2000s represents neo-liberalism's pinnacle, and the gains of the early republic, especially laicism, continued to be eroded under the model of moderate Islamism. Post-modernism, constructivism, and individualism provided a perfect apparatus for reactionaries to dilute the positivist values of Ataturk's republican tradition, while shaping a more neo-liberal curriculum.

Ataturk believed that the safeguarding of the principles of the young republic, social change, and economic development could only happen through education. In this sense, Santoro and Dorn (2012) compare Ataturk to some of America's revolutionary leaders such as Jefferson, Madison and Hamilton. Ataturk believed in an education system that represented the values of the Enlightenment ideology such as universalism, rationality, objectivity, scientism, secularism, optimism. This was evident in his speeches and programs. For instance, one of his most famous aphorisms is that "the only guide in life is science". Ataturk was optimistic about the country's future by setting a goal for the Turkish youth to reach the highest level of civilization.

However, as many sociologists have asserted, the challenge of the Turkish modernism and secularism project was that it was not grown out of society, it was given to society (Akural 1984; Steinbach 1984). To use the cliché, it was 'top down' reform. As such it was not so different from all comparable reform efforts in the West. According to Steinbach, only the intellectuals and bureaucratic elites who benefited from the system identified themselves with Kemalism, while traditionalists and the masses did not connect to this idea. Similarly, Akural points out that the

Kemalist project was not organically grown concept as functionalists define, without internal stresses and conflicts a complete social change would not be possible. Even though the "populism" principle of Kemalism aimed at absolute equality of citizens before the law, some of the old feudal structures (agalik) were difficult to change because of the land owning senators. Further, Kemalism failed to establish a welfare system to facilitate the overturn of this feudal structure, especially in eastern Turkey (Akural 1984).

Despite all the initial problems associated with the devastated economy after the independence war of the 1920s, an overwhelmingly uneducated peasant society, a strong feudal tradition, and religious conservatism, the Turkish modernity project can be seen as more of a success than a failure. The Turkish modernization project resulted in a number of successes including the establishment of a secular national state with a relatively stable democratic political system. This modernization saw the development of a strong sense of national identity, the preservation of traditional and local culture, and the growth of transportation, mass media, communication, schooling rates, and a variety social, cultural, political and other interest groups (Weiker 1981).

On the other hand, the top-down approach of the Kemalist modernization project caused long lasting political tensions between the secularists and traditionalists (Gulalp 2005). When one considers the unique secular model of Turkey, where religion is subjugated to (but not entirely separated from) the state (Davison 1998), one sees a dialectical relationship between the two; it is a relationship in which it is sometimes questionable which controls the other, as exemplified by the mandate for religious education. A tension arises between the secularists, who want to protect the public sphere and create a critical discourse concerning the traditional forces (Outram 2013), and the Islamists, who want use the same public space to "live" their religion (Turkmen 2012).

The inseparable nature of religion from the state, the public sphere, and other realms of life suggests that if any enlightenment can be assumed in this context it should be the "moderate enlightenment" (Israel 2006) where reason is combined with faith and tradition as opposed to where the reason is the only guiding truth. As presented earlier, Kucuk (2012) and Akkach (2007) noted the existence of this phenomenon with different but similar terms for the seventeenth century Ottoman Empire. This trend seems to be continuing in today's society where there is a strong conservative tradition.

Islamists in Turkey have long blamed the secular state for its authoritarianism that interfered with their tradition. Today, secularists are more concerned with the increasing influence of political Islamism in public life and the resulting lack of religious toleration. Somer (2007) argued that democratic consolidation – the idea of strengthening democracy so that it is unthinkable for the great masses to reverse the gains of democracy – can be a viable model to protect secularism. Only in a democratic and secular society can the Turkish Enlightenment tradition be furthered; without such protection, the gains of free speech, gender equality, non-preferential treatment of any religion, universal education, can all be rolled-back and legislated away.

The Enlightenment should not be seen as a closed historical period, neither in the West or in in non-Western societies (Outram 2013). Conflicts between Enlightenment-informed science education and conservative, reactionary forces exist today in Turkey as we documented here and in many other countries around the world (Matthews 2015b), particularly in the Middle East (Nielsen 2016). The antidote for the counter-Enlightenment and reactionary movements is a vigorous, serious, and national science education because good science education develops citizens with critical and informed habits of mind who value reason, who acknowledge the importance of gathering evidence and testing beliefs, who affirm the necessity of open public discussion and debate, who deny all illegitimate claims to epistemic authority concerning the natural and social worlds. But, denying illegitimate claims to scientific authority means affirming legitimate ones; and a challenge of constructivist and relativist accounts of science is to see how they can identify and support the latter. If all sciences and methodologies are equal, then there can be no legitimate or authoritative science; surely a debilitating conclusion for science teachers and advocates.

Acknowledgement We thank Michael Matthews, the editor, and anonymous reviewers for their very helpful feedback and Greg Blalock for his careful reading of the manuscript.

References

Ak, G. (2015). Turk dusunce hayatinda Mediha Esenel (Berkes) ve 1948 DTCF tasfiyeleri iliskisi uzerine bir inceleme. *Journal of Modern Turkish History Studies, XV/30*, 251–293.

Akkach, S. (2007). *Makers of the Muslim world- 'Abd al-Ghani al-Nabulusi: Islam and the enlightenment*. Oxford: Oneworld Publications.

Akural, S. M. (1984). Kemalist views on social change. In J. M. Landau (Ed.), *Ataturk and the modernization of Turkey* (pp. 125–152). Boulder: Westview Press.

Akyuz, Y. (1999). 17. Yüzyıldan Günümüze Türk Eğitiminde Başlıca Düzenleme ve Geliştirme Çabaları: Genel Özellikler ve Doğrultular, *Milli Eğitim Dergisi [Journal of National Education]*, 144.

Altin, H. (2008). 1869 Maarif-i Umumiye Nizamnamesi ve Öğretmen Yetiştirme Tarihimizdeki Yeri. *Fırat Üniversitesi İlahiyat Fakültesi Dergisi, 13*(1), 271–283.

Altunya, N. (1999). *Türkiye Cumhuriyeti'nde Din Eğitimi, 75 Yılda Eğitim* (Gök, F. Ed.). (s:215–222). İstanbul: Tarih Vakfı Publications.

Anadolu Agency. (2015). *İmam hatip lisesi sayısını 440'dan 1017'ye çıkardık*. http://www.hurriyet.com.tr/egitim/28069550.asp. Accessed 15 June 2015.

Arayici, A. (1999). *Kemalist Dönem Türkiye'sinde Eğitim Politikaları ve Köy Enstitüleri*. İstanbul: Ceylan Yayınları.

Ata, B. (2000). The influence of an American educator (John Dewey) on the Turkish Educational System. *The Turkish Yearbook of International Relations, 31*, 119–130.

Ayas, R., & Tümer, G. (1994). *Liseler için Din Kültürü ve Ahlak Bilgisi I* [*Religion and Ethics for High Schools I*]. Ankara: Milli Egitim Basimevi [Ministry of Education Publications].

Bademci, G. (2006). First illustrations of female "neurosurgeons" in the fifteenth century by Serafeddin Sabuncuoglu. *Neurocirugia, 17*, 162–165.

Berk, O. (2007). Batilasma ve Ceviri (westernization and tranlastion). In T. Bora & M. Guntekingil (Eds), *Modern Turkiye'de Siyasi Dusunce*, Vol 3: Modernlesme ve Baticilik, (pp. 511–520). Istanbul: Iletisim.

Berkes, N. (1998/1964). *The development of secularism in Turkey*. London: C. Hurst & Publishers Ltd.

Berkes, N. (2002). *Türkiye'de çağdaşlaşma.[Turkey's Coming of Age].* İstanbul: Yapı Kredi Publications.
Bilgi, S., & Ozsoy, S. (2005). John Dewey's travelings into the project of Turkish modernity. In T. S. Popkewitz (Ed.), *Inventing the modern self and John Dewey: Modernities and the traveling of pragmatism in education* (pp. 153–177). New York: Palgrave Macmillan.
Birol, S. (2012). 1961 Anayasasinda ifade ozgurlugu. *Istanbul Universitesi Iletisim Fakultesi Dergisi, 43*, 39–54.
Bohannon, J. (2016). Update: Vacationing Turkish scholar arrested after her return. *Science*. doi:10.1126/science.aaf9817.
Caliskan, N. (2015). *ODTU Tarihce: 1956–1980*. Istanbul: Propoganda Yayinlari.
Cinar, A., Roy, S., & Yahya, M. (2012). Religious nationalism as a consequence of secularism. In A. Cinar & S. Roy (Eds.), *Visualizing secularism and religion : Egypt, Lebanon, Turkey, India* (pp. 1–22). Ann Arbor: University of Michigan Press. Retrieved from http://www.ebrary.com.
Davidson, N. (2006). Islam and the enlightenment. *Socialist Review*. http://socialistreview.org.uk/304/islam-and-enlightenment. Accessed 4 Mar 2015.
Davison, A. (1998). *Secularism and revivalism in Turkey: A hermeneutic interpretation*. New Haven: Yale University Press.
Dere, M. (2008). *Türkiye'de azınlık okulları (1945–2007). [Minority Schools in Turkey].* Unpublished Master Thesis Sosyal Bilimler Enstitüsü, Niğde University.
Dergisi, T. (1957). *Liselerin yeni müfredat programı hakkında, Cilt: 20 Sayı: 976*. Ankara: Milli Eğitim.
Devlet Planlama Teskilati (DPT). (1983). *Milli Kültür Özel İhtisas Komisyonu Raporu*, Yayın no: DPT: 1920-ÖİK: 300, Ankara.
Dewey, J. (1924a). *From The Collected Works of John Dewey, 1882–1953, The Middle Works of John Dewey, 1899–1924,* Volume 15: 1923–1924, Essays [Page mw.15.274, blank] [Page mw.15.275] https://chipbruce.files.wordpress.com/2008/10/dewey_turkey.pdf. Accessed 10 Apr 2015.
Dewey, J. (1924b). Secularizing a theocracy: Young Turkey and the Caliphate. *New Republic, 40*, 69–71.
Dewey, J. (1924c). Angora, the New. *New Republic, 40*, 169–170.
Dewey, J. (1924d). The Turkish Tragedy. *New Republic, 40*, 268–269.
Dewey, J. (1925). Foreign schools in Turkey. *New Republic, 41*, 40–42.
Dreyfuss, R. (2005). *Devil's game: How the United States helped unleash fundamentalist Islam*. New York: Henry Holt and Company, LLC.
Durmus, Ö. Z. (2013). Cumhuriyet dönemi fen eğitimi dokümanlarında bilim konusunda değişim: Tarihsel yorumlamacı bir içerik analizi. Unpublished Master Thesis. Marmara University.
Edis, T. (1999). Cloning creationism in Turkey. *Reports of the National Center for Science Education, 19*, 30–35.
Edis, T., & BouJaoude, S. (2014). Rejecting materialism: Responses to modern science in the Muslim Middle East. In M. Matthews (Ed.), *International handbook of research in history, philosophy and science teaching* (pp. 1663–1690). Dordrecht: Springer.
Eskicumali, A. (2003). Eğitim ve Toplumsal Değişme: Türkiye'nin Değişim Sürecinde Eğitimin Rolü (1923 – 1946). [Education and Social Change: The role of education in Turkey's change process]. *Boğaziçi Üniversitesi Eğitim Dergisi [Boğaziçi University Journal of Education], 19* (2), 15–29.
Gay, P. (1970). *The enlightenment: An interpretation. The rise of paganism*. London: Weidenfeld and Nicolson.
Georgeon, F. (2006). *Osmanli-Turk Modernlesmesi 1900–1930: Secilmis Makaleler* [*Ottoman-Turkish modernization: selected articles*]. Istanbul: Yapi Kredi Kultur Sanat Yayincilik.
Gulalp, H. (2005). Enlightenment by fiat: Secularization and democracy in Turkey. *Middle Eastern Studies, 41*(3), 351–372.
Guleryuz, N. A. (2008). *Turkiye'ye gelen cogu Yahudi kokenli Alman prosesorler ve Albert Einstein*. *Şalom*. http://www.salom.com.tr/haber-64078-turkiyeye_gelen_cogu_yahudi_kokenli_alman_profesorler_ve_albert_einst.html. Accessed 25 Apr 2016.
Gunal, İ. (2013). *50 soruda üniversite. [University in 50 questions].* İstanbul: Bilim ve Gelecek Yayınları.

Gunal, S., & Gunal, I. (2011). Üniversitelerde örgütlenme deneyimi. In F. Ercan & S. Kurt Korkusuz (Eds.), *Metalaşma ve İktidarın Baskısındaki Üniversite* (pp. 555–564). İstanbul: Sosyal Araştırmalar Vakfı Publications.

Howard, D. A. (2001). *History of Turkey*. Westport: Greenwood Press. Retrieved from http://www.ebrary.com.

Ihsanoglu, E. (2006). An overview of Ottoman scientific activities. http://www.muslimheritage.com/uploads/An_Overview_of_Ottoman_Scientific_Activities1.pdf Accessed 26 Mar 2016.

Inal, K., Akkaymak, G., & Yıldırım, D. (2014). The constructivist curriculum reform in Turkey in 2004 – In fact what is constructed? *Journal for Critical Education Policy Studies, 12*(2), 350–373.

Inonu, E. (1998). *Anılar ve düşünceler,* 1.cilt. İstanbul: Boyut Publications.

Israel, J. I. (2001). *Radical enlightenment: Philosophy and the making of modernity 1650–1750*. Oxford: Oxford University Press.

Israel, J. I. (2006). *Enlightenment contested: Philosophy, modernity, and the emancipation of man 1670–1752*. New York: Oxford University Press.

Israel, J. I. (2011). *Democratic enlightenment: Philosophy, revolution, and human rights, 1750–1790*. Oxford: Oxford University Press.

Karaomerlioglu, A. (2009). Koy Enstituleri. In T. Bora & M. Gultekingil (Eds.), *Modern Turkiye'de Siyasi Dusunce*, *Kemalism* (Vol. 2, pp. 283–293). Istanbul: Iletisim.

Kirby, F. (2000). *Türkiye'de Köy Enstitüleri*, 2. baskı, Ankara: Güldiken Yayınları.

Korkut, H. (2003). Turkiye'de cumhuriyet doneminde universite reformlari. Milli Egitim Dergisi, Sayi 160. http://dhgm.meb.gov.tr/yayimlar/dergiler/Milli_Egitim_Dergisi/160/korkut.htm. Accessed 5 May 2016.

Korlaelci, M. (2009). Positivist dusuncenin ithali. In T. Bora & M. Guntekingil (Eds.), *Modern Turkiye'de Siyasi Dusunce: Cumhuriyete Devreden Dusunce Mirasi-Tanzimat ve Mesrutiyetin Birikimi* (pp. 214–222). Istanbul: Iletisim.

Kucuk, B. H. (2012). *Early enlightenment in Istanbul*. San Diego: University of California.

Matthews, M. R. (2015a). *Science teaching: The contribution of history and philosophy of science: 20th anniversary revised and expanded edition (Second)*. New York: Routledge.

Matthews, M. R. (2015b). Reflections on 25 years of journal editorship. *Science & Education, 24*, 749–805.

MEB (2006). *Ilkogretim Fen ve Teknoloji Dersi Mufredati*. http://ttkb.meb.gov.tr/program2.aspx. Accessed 25 Nov 2015.

Muftuoglu, O. (2012). Labor markets in the process of restructuring 4+4+4 formula. *Education, Science Society Journal, 10*(40), 25–33.

Mugaloglu, E. Z., & Bayram, H. (2009). Do religious values of prospective teachers affect their attitudes toward science teaching? *Journal of Turkish Science Education, 6*(3), 90–96.

Nielsen, R. (2016). *Teaching evolution in the Middle East* [Blog]. Nielsen Lab Blog. http://www.nielsenlab.org/2016/02/teaching-evolution-in-the-middle-east/. Accessed 10 June 2016.

NRC (National Research Council). (1996). *National science education standards*. Washington, DC: National Academy Press.

Odatv. (2015). *YOK'ten universitelere talimat Suriyelileri arastirmak yasak.* http://odatv.com/suriyelileri-arastirmak-yasak-0605151200.html. Accessed 20 Nov 2015.

OECD. (2014). PISA 2012 *Results in Focus: What 15-year-olds know and what they can do with what they know: Key Findings*. http://www.oecd.org/pisa/keyfindings/pisa-2012-results-overview.pdf. Accessed 25 Nov 2015.

Oguzkan, A. F. (1990). *Kuruluşunun 50. yılında Köy Enstitüleri* (pg. 12–37). Ankara: Eğit-Der Publications.

Okcabol, R. (2005). *Türkiye Eğitim Sistemi*. [Turkish education system]. Ankara: Ütopya.

Oncu, A. (2007). Akademisyenler: Universite reform soyleminde bati. In T. Bora & M. Gultekingil (Eds.), *Modern Turkiye'de siyasi dusunce*, vol 3: Modernlesme ve Baticilik, (pp. 521–536). Istanbul: Iletisim.

Outram, D. (2013). *The enlightenment: New approaches to European history*. Cambridge: Cambridge University Press.

Patiniotis, M., & Gavroglu, K. (2012). The sciences in Europe: Transmitting centers and the appropriating peripheries. In J. Renn (Ed.), *The globalization of knowledge in history*, (pp. 321–343). Edition Open Access: Max Planck Research Library for the History and and Development of Knowledge.

Peker, D., Comert, G. G., & Kence, A. (2010). Three decades of anti-evolution campaign and its results: Turkish undergraduates' acceptance and understanding of the biological evolution theory. *Science and Education, 19*(6–8), 739–755.

Santoro, D. A., & Dorn, C. (2012). A vital, free, independent, and lay republic. In R. Garlitz & L. Jarvinen (Eds.), *Teaching America to the world and the world to America: Education and foreign relations since 1870*. New York: Palgrave MacMillan.

Sayın, U., & Kence, A. (1999). Islamic scientific creationism: A new challenge in Turkey. *Reports of the National Center for Science Education, 19*, 18–29.

Somel, S. A. (2005). Christian community schools during the Ottoman reform period. In E. Özdalga (Ed.), *Late Ottoman Society: Intellectual legacy* (pp. 257–276). New York: RoutledgeCurzon.

Somer, M. (2007). Moderate Islam and secularist opposition in Turkey: Implications for the world, Muslims and secular democracy. *Third World Quarterly, 28*(7), 1271–1289.

Steinbach, U. (1984). The impact of Ataturk on Turkey's political culture science World War II. In J. M. Landau (Ed.), *Ataturk and the modernization of Turkey* (pp. 77–87). Boulder: Westview Press.

Taskın, O. (2005, October 8). New science curriculum in Turkey. *Cumhuriyet Newspaper, Bilim Teknik, 968*, 20–22.

Taskin, O. (2011). Can willingness and hands-on work together? Teaching biological evolution and dealing with barriers. *Evolution Education and Outreach, 4*(3), 467–477.

Taskin, O. (2013). Pre-service science teachers' acceptance of biological evolution in Turkey. *Journal of Biological Education, 47*(4), 200–207.

Tekeli, İ., & Ilkin, S. (1993). *Osmanlı İmparatorluğu'nda eğitim ve bilgi üretim sisteminin oluşumu ve dönüşümü*. Ankara: Türk Tarih Yüksek Kurumu Yayınları.

Toker, N., & Tekin, S. (2007). Batici siyasi dusuncenin karakteristikleri ve evreleri: "Kamusuz Cumhuriyet"ten "Kamusuz Demokrasi'ye", In T. Bora & M. Gultekingil (Eds.), *Modern Turkiye'de siyasi dusunce,* vol 3: Modernlesme ve Baticilik (pp. 82–106). Istanbul: Iletisim.

Toprak, Z. (2011). Darwinizmden Ateizme Türkiye" de Tarih Eğitiminin Evrimi. *Toplumsal Tarih, 216*, 20–33.

Turkmen, B. (2012). Islamic visibilities, intimacies, and counter publics in the secular public sphere. In A. Cinar & S. Roy (Eds.), *Visualizing secularism and religion: Egypt, Lebanon, Turkey, India*. Ann Arbor: University of Michigan Press. Retrieved from http://www.ebrary.com.

Ugur, M. (2016). *Academic freedom under threat in Turkey. Times Higher Education.* https://www.timeshighereducation.com/features/academic-freedom-under-threat-in-turkey. Accessed 2 June 2016.

Weiker, W. F. (1981). *The modernization of Turkey: From Ataturk to the present day*. New York: Holmes & Meier Publishers Inc.

Yalcinkaya, M. A. (2015). *Learned patriots: Debating science, state, and society in the nineteenth century Ottoman Empire*. Chicago: University of Chicago Press.

Yildirim, N. (2014). A view of the history of the Istanbul Faculty of Medicine. http://istanbultip.istanbul.edu.tr/en/wp-content/uploads/2014/06/historyofimf.pdf. Accessed 11 May 2016.

Yılmaz, A., & Morgil, İ. (1992). Türkiye'de Fen Öğretiminin Genel Bir Değerlendirmesi Sonuçları ve Öneriler. *Hacettepe Üniversitesi Eğitim Fakültesi Dergisi, 7*, 269–278.

Chapter 4
Cultural Studies of Science Education: An Appraisal

Christine L. McCarthy

4.1 Introduction

The Cultural Studies of Science Education (CSSE) became prominent in 2006 with the launching of the Springer journal of the same name. The field has in the past decade developed a congeries of inter-related theses about the nature of modern science as a human activity and correspondingly of science education. Yet some of the theses most deeply entrenched in CSSE scholarship actively obstruct the role of scientific inquiry in providing genuine knowledge[1] of the dynamic interactions that constitute the world (or the universe, reality, existence, or simply, *what is*).[2] Science education, if it is to serve both its intellectual and social purposes, must be undergirded by a sound conception of the general nature of the process of modern scientific inquiry, and an understanding of the nature and value of scientific knowledge.

Developing a thorough knowledge of the determining factors of physical and social problems through the process of scientific inquiry is a necessary condition for developing, testing and refining active solutions to those problems. Developing a widely shared cultural consensus on the value of scientific knowledge and hence of scientific method is also necessary, if in a democratic society the political will is to be gathered to take social action based on that knowledge. One of the cultural purposes of primary and secondary science education is to lay the groundwork necessary for building that social consensus.

But, there is currently a disturbing disinclination, in some quarters, to see modern scientific inquiry and knowledge as relevant to solving social/cultural/physical problems. Cordero, in 2001, states that modern science offers an account the world

[1] Epistemological questions regarding the characterization of knowledge are taken up later in the chapter.

[2] See McCarthy 2014 and McCarthy 2017.

C.L. McCarthy (✉)
College of Education, University of Iowa, Iowa City, IA, USA
e-mail: christine-mccarthy@uiowa.edu

M.R. Matthews (ed.), *History, Philosophy and Science Teaching*, Science: Philosophy, History and Education, DOI 10.1007/978-3-319-62616-1_4

that in its detail and coherence is so far superior to other accounts that "A scientific culture is correspondingly on the rise, centered on this [scientific] picture and its attendant style of thinking" (p. 2001). Cordero also notes that "Opposition to according science special intellectual prominence is not in short supply" (p. 18). It seems that currently the opposition to the knowledge generated by modern science is in many quarters culturally ascendant. I will argue that the prevalence in science education of erroneous post-modern interpretations of the nature of science, the nature of knowledge, and the nature of truth contribute to the social problem of cultural disdain for, or neglect of, modern science, its practices and its findings.

Wolpert (1992) argues that the scientific attitude, the inclination to engage in extended experimental inquiry to reach well-warranted beliefs about the world, is an attitude that generally requires cultural inculcation. Given the stringent norms of science proper, Wolpert argues, the scientific attitude is unlikely to arise naturally, in the absence of extensive education in and about science. That education is difficult to achieve, because understanding scientific inquiry requires understanding complex sets of abstract theoretical formulations about the dynamics of the world. The scientific knowledge about the world that is achieved tends to be highly counterintuitive. While it is not to be expected that all students will become scientists, in a modern society all students should develop a basic comprehension of the scientific inquiry and knowledge upon which the society depends. In the absence of a general commitment to high quality science education, the general scientific competence in a society is likely to be insufficient to promote, and to demand, the use of scientific knowledge as the essential guide to social policy.

It is hard to say which is more incongruous, the turn against modern science in scientifically advanced countries, or the same phenomenon in countries most urgently in need of scientific advancement. The global spread of the anti-science attitude has the potential to lead to social, environmental and/or economic disasters of unprecedented proportions.

In Part I, I briefly set out a significant social problem, global warming, that is exacerbated by anti-science ideologies, and I introduce the cultural studies of science education (CSSE). In Part II, I examine prominent post-modern theses commonly held in, and characteristic of, the field of CSSE. I argue that acceptance of these post-modern theses is antithetical to the development of genuine scientific knowledge, and to the application of scientific method and knowledge to urgent social/cultural crises. In Part III, I argue that there is a set of philosophical positions that is conceptually essential to the understanding of genuinely modern science, and antithetical to central CSSE theses. This set includes naturalism, ontological realism, a correspondence conception of truth, and a naturalistic conception of knowledge.[3]

[3] I shall use the term 'modern science' to indicate inquiries and the results thereof that conform to the philosophical/social norms of science. The term 'modern science' is used normatively, referring to science properly so-called.

4.1.1 Anti-science in Contemporary U.S. Culture

Recent news reports in the United States on global warming should be alarming to proponents of modern science. The scientific consensus on the human causation of global warming is well established. A comprehensive account of the scientific consensus is available, in Stocker et al. (2014). Despite the scientific consensus, anti-science ideology in the U.S. Federal government is politically influential. Major U.S. Federal House and Senate committees charged with deciding on issues of national science policy are led by politicians who reject the consensus of modern science, generally for religious reasons (see Bradley 2011). The position of Senator Jim Inhofe (R., Oklahoma) is an example. Inhofe is the Chair of the Senate Committee on the Environment and Public Works. Inhofe "has called climate change 'the greatest hoax ever perpetrated on the American people' and compared the EPA [Environmental Protection Agency] to the Gestapo" (2014 Nov 15 From the Economist, *Climate Change: Dealing with Denial*).

Donald Trump, while a Presidential candidate, provided another example. During an interview by the editorial board of *The Washington Post*, Trump stated:

> I think there's a change in weather. I am not a great believer in man-made climate change. I'm not a great believer. There is certainly a change in weather that goes—if you look, they had global cooling in the 1920s and now they have global warming, although now they don't know if they have global warming … Perhaps there's a minor effect, but I'm not a big believer in man-made climate change.[4]

Other highly placed deniers of human caused global warming include: Congressman Paul Ryan (R. Wisconsin), House Majority Leader; Senator Lisa Murkowski (R. Alaska), Senate Committee on Energy and Natural Resources; Congressman Fred Upton (R. Michigan), Chair, House Energy and Commerce Committee; Senator Mitch McConnell (R. Kentucky), Senate Majority leader; and Congressman Lamar Smith, Chair of the House Committee on Science, Space and Technology.[5] The anti-science attitude of corporate entities primarily concerned with expanding the wealth and power of the corporation, though deplorable, is not surprising. But it is surprising that voters in the U.S. would repeatedly elect persons with strong anti-science platforms to positions in the federal government. Cultural antipathy toward science is a troubling state of affairs, when the effective amelioration of current social problems is the overall goal. Though the causal factors contributing to the anti-science ideology are many and diverse, one point of intervention

[4] https://www.washingtonpost.com/blogs/post-partisan/wp/2016/03/21/a-transcripteditorial board-of-donald-trumps-meeting-with-the-washington-post-editorial-board/

[5] For a fuller account, see Dunlap and McCright (2014), Merchant (2015), and also

http://www.joanneoellers.com/wp-content/uploads/2014/03/Republican-and-Democratic-Views-on-Climate.pdf

http://www.environmentmagazine.org/Archives/BackIssues/September-October 2008/dunlap-full.html

http://thinkprogress.org/climate-denier-caucus-114th-congress/ http://thinkprogress.org/climate/2013/12/11/3045841/house-science-hearing-weather-climate/

could be the science education efforts in the U.S. public schools. Yet current trends in science education, arising in the CSSE literature, are inconsistent with the nature of science, properly conceived.

4.1.2 Cultural Studies of Science: Re-conceptualizing Science and Science Education

Ken Tobin, in his ‘Connecting science education to a world in crisis’ (Tobin 2015), maintains that the global crises currently facing the world cannot be adequately addressed unless science educators adopt a new position on the logic of science, a position which Tobin calls “multilogicality”. Tobin’s multilogicality, intended to provide for openness to multiple and diverse cultural beliefs in the context of science education, seriously misconstrues the nature of modern science.

Tobin makes the claim that, currently, much of science education suffers from an outdated “adherence the tenets of crypto-positivism” (Tobin 2015), and that this creates problems for research in the social sciences.[6] For example, an “over reliance on statistical analyses leads to oversimplified modes that strip away context and are reductive…. Hypotheses and associated statistical tests support causal models that rarely predict social conduct…” (Tobin 2015).

In response to the inadequacies of what are conceived as positivistic scientific methods, Tobin develops the notion of “a multilogical methodology that embraces incommensurability, polysemia, subjectivity, and polyphonia as a means of preserving the integrity and potential of knowledge systems to generate and maintain disparate perspectives, outcomes and implications for practice” (Tobin 2015).

The stated aim of a multilogical method raises concern. Multilogical method is described as “a means of preserving the…potential of knowledge systems to generate and maintain disparate perspectives, outcomes and implications for practice…” (Tobin 2015). The project of acquiring an objective scientific knowledge of the world seems to be denied by Tobin. Tobin seeks to maintain disparity in beliefs about the world, and considers this state of confusion about the interactive dynamics of the world to be a good thing, and the goal of scientific inquiry. Why?

The answer seems to be Tobin’s rejection of “power discourses“. Tobin writes:

> In such a multilogical model, power discourses such as Western medicine carry no greater weight than complementary knowledge systems that may have been marginalized in a social world in which monosemia is dominant. (Tobin 2015).

The consequences of Tobin’s re-conception of science can be dire. Consider, for example, its consequences in the current social crisis due to the spread of the Zika virus by the *Aedes eagypti* mosquito. Modern medicine (sometimes called “Western” medicine, despite its global range) has identified a connection between the Zika

[6] For an account of the all-to-common misconstrual of positivism in education writing, see Matthews (2004).

virus and the development in utero of microcephaly in infants. Alternative beliefs about this threat to health may arise from "ways of knowing" other than scientific inquiry. Unwarranted beliefs about the causes of the microcephaly epidemic will serve to exacerbate the crisis. Tobin, though, "accept[s] poly-ontology (i.e., the co-occurrence of multiple realities/many ways to answer the question: What happened?)" (Tobin 2015). While it is possible that many different and conflicting opinions about the causes of the Zika situation can be generated, it remains the case that the causal interactions that constitute the medical crisis are real, and can be known, in principle, via scientific inquiry. It should not need stating, at this point in the progress of modern science, that only inquiry that is conducted according to scientific norms has the potential to ameliorate the problem: at a given time there may be more than one scientific answer to the question, and all such answers will depend upon social and political support in order to be acted upon. But none of this is to say that *all* opinions on the etiology and means of transmission of the Zika virus are equally true or worthy of funding.

What are the conceptions of the nature of scientific inquiry and of scientific knowledge that are advanced in the theoretical literature in the cultural studies of science education? I will address this question next, and argue that the central philosophic theses underlying the cultural studies of science and science education actually undermine development of true beliefs about the nature, methods and results of science.

4.2 Postmodernism and the Cultural Studies of Science Education

4.2.1 The Postmodern World-View

The postmodern worldview presents numerous variations on its basic theses. I will set out several post-modern theses that are prominent in the context of science and science education.

In *The Reenchantment of Science: Postmodern Proposals*, Griffin calls for a "constructive post-modernism" that will reverse the disenchantment of the world wrought by modern science and scientific knowledge; this disenchantment is said to be due to "the denial to nature of all subjectivity, all experience, all feeling…" (Griffin, in Griffin, (ed.,) 1988b, p. 2). Harman (in Griffin, (ed.), 1988a) sets out "… the 'secret' [that] has been more and more openly shared: *Experienced reality does not conform to the 'reality' they taught us in science class; the 'scientific worldview' is not an adequate guide for living life or for managing a society"* (Harman 1988, p.122, emphasis in original). Harman calls for development of a "complementary science" that would "take as its particular focus subjective experience, consciousness…purpose, value choices, ...alternate states of consciousness, [and] particularly 'deep intuition'" (Harman 1988, p. 123), among a long list of other subjective mind-based foci.

Harman states: "Whereas the implicit assumption in positivistic science is that the basic stuff of the universe is matter-energy, this alternate approach makes a different assumption: *The basic stuff of the universe exhibits two fundamentally different kinds of properties: matter-energy properties and mind-spirit properties*" (Harman 1988, p. 123, emphasis in the original). The post-modern view Harman promotes returns to the substantial dualism of Descartes, a duality of Mind and Matter, somehow conjoined and interactive. This view is unsupported by modern science, and thus is counterproductive in the teaching of science.

Farrell (1996) takes a different tack, critically examining the historical development of post-modernism, and analyzing its radical departure from the world-view of the modern period. Farrell posits three potential sources of power that serve to determine the beliefs of persons. These are: (1) the world; (2) the self; and (3) the culture. According to Farrell, in a modern society, the principal determinative factor is considered to be the world (reality, what is). In a postmodern society the principal determinative factor is considered to be the culture (cultural practices, linguistic discourse, established beliefs). Farrell finds this change in emphasis to be the "standard move" in postmodern thought. Postmodernists emphasize culture as the determinative factor in fixing belief, and to such a radical extent that the other two factors largely drop out of the picture.

Farrell gives a number of examples of this, but one is particularly pertinent: "Did the scientist match his beliefs with what reality is like? No, says Rorty. He made his beliefs conform with what conversational practices had frozen as the background that fixed what everyone would count as real" (Farrell 1996, p. 249). For the postmodernist thinker, "all determinative power flows to the position of cultural practice and interpretation" (Farrell 1996, p. 249). Postmodernism is "inflating the role of cultural practices so radically that world and self virtually disappear as constraints on those practices or as measures of their success" (Farrell 1996, p. 249).

Farrell's description of postmodernism fits well with the thesis common in the CSSE literature that all forms of knowledge, and even scientific knowledge, are mere dogmatically held cultural beliefs; there is little if any place for the world in driving theory commitment or theory change; it is all a matter of intracultural negotiation. The culturally-set beliefs need not be subjected to the continual critique, via the experimental testing that is definitive of genuine scientific knowledge. In all cultures, the dissemination of knowledge is necessarily a matter of cultural products—e.g., books, journals, web sites, etc.—but, the process of achieving knowledge via ongoing scientific experimental inquiry distinguishes modern scientific culture from postmodern culture.

4.2.2 Re-constructing Science

The radical re-conceptualization of the concept of science and the subsequent reconstruction of science education are key intellectual aims of the literature that makes up cultural studies of science education. (See, for example, Irwin & Bednarz

(1998), Roth & Barton (2004), LaRochelle et al. (2009) and Sefa Dei (2011).) Roth et al. (2001) set out their view succinctly. "Science is viewed as a discourse that is a relatively recent activity of humankind, the goal being to make sense of a universe of phenomena in terms of knowledge that is viable" (Roth, Tobin & Ritchie 2001, p. 218).

Examined closely, this statement provides a great deal of information about the CSSE conceptualization of science. "Science is viewed as a discourse…". Science is conceived as a culturally based set of discursive practices that human beings sometimes engage in. The authors make no mention of the activity of experimental inquiry. The goal of a discursive science is "to make sense of a universe of phenomena". The authors make no mention of the discovery of real causal relationships existing among thing/events in the world, which determine the occurrent and possible interactions in a localized natural system. The goal of science, as described by Roth, Tobin, and Ritchie, is subjective; the goal is to develop ideas that make sense to certain persons, or, more broadly, to certain cultures. But, in the absence of the ongoing experimental testing characteristic of modern scientific inquiry, there is an endless number of different and mutually exclusive sets of ideas that might "make sense", subjectively, to different persons and cultural groups. Absent commitment to modern science, individuals and cultures can be expected to develop and accept radically different ideas about interactivities that constitute the universe. And, absent the commitment to modern scientific inquiry, with its acceptance of the fallibility of knowledge, demonstrably false beliefs are likely to be dogmatically held.

Roth et al. (2001) describe the universe as a universe of phenomena. The term 'phenomena'serves to indicate the presence of active meaning-making subjects whose interpretation of experienced events is in large part determined by their own conceptual structures, or by the culturally inculcated core beliefs. It is the subjects' experiences that must be made to make sense; the universe as it is in itself apart from the contribution of the experiencing subject is considered to be inaccessible. As such, it cannot be objectively known, nor even known to exist.

The concept of 'knowledge' appears in Roth, Tobin and Ritchie's conception of science. They specify that this knowledge is to be "viable", and make no mention of its needing to be judged to be true, or likely to be true, on the basis of compelling reasons. The concept of viability as the defining characteristic of knowledge is a thesis developed in von Glasersfeld's (1993) 'Questions and Answers about Radical Constructivism' where he writes "Truth in constructivism, as I keep repeating, is replaced by viability" (Glasersfeld 1993, p. 25). When knowledge is conceived as any belief-system that meets the criterion of viability, it follows that any longstanding, "time-tested" system of cultural belief must be counted as knowledge. As each culture has its own historically developed body of such beliefs, each culture has its own knowledge. The body of cultural belief, developed by any sort of method and tested only by its endurance over time, is to be considered, in the postmodern/cultural studies worldview, to be the "science" of that culture.

On this view, "science" is any process occurring in a culture that is causally active in developing the longstanding beliefs of the culture. It matters not what methods are employed to fix upon the body of belief that comes to be accepted by the larger cultural community. The method of fixing belief could involve the retelling of traditional stories, or the study of revelations believed to reside in a sacred text. Or, the fixed belief may have come in a dream, or by intuition. All methods are to be held equally productive of "knowledge", in the sense of longstanding cultural belief, and therefore all are held to be equally "scientific", in the new sense.

In the CSSE literature, social justice is taken to require that long-standing belief systems of all cultures be respected equally as bona fide knowledges, particularly by the "Western" scientific culture. This is an odd requirement. It is motivated, it seems, by the idea that long-standing belief systems must be getting *something* right, given that the societies in question have persisted, "successfully", for very long time-spans.

Modern science, in contrast, is recognized to be a quite recent form of activity. And, because of the commitment of modern science to continual testing and revision of the body of knowledge acquired, both the methods of inquiry and the conclusions of inquiry are continually changing. The most current science of the present day is substantially different from the science of previous centuries. So, the criterion of "long-standing-ness" would serve to rule out modern science as knowledge. What is in fact the most advanced knowledge would thus be judged not to be knowledge at all. Yet, in the cultural studies of science education literature, calls are made for the inclusion of long-standing cultural belief systems and methods of "inquiry", in the science education classroom (see McCarthy 2014).

It is considered necessary in the CSSE literature to hold that there is a multiplicity of culturally based knowledges, many of which will be mutually inconsistent, and thus mutually exclusive, or would be, if the concept of correspondence truth were in the picture. It is clearly true that fundamentally different conceptions of the dynamic interactions of the world exist, in the various cultures and sub-cultures created by human beings. But the fact of culturally based epistemic diversity does not determine the cognitive value of the accepted conceptions of the world.

The CSSE pedagogical implication is that, in science education, a rich array of different knowledges should be offered in the classroom, from which each student may choose. The only criterion of choice, once a correspondence theory of truth is rejected, is that the chosen knowledge system either has utility for or makes sense to the individual; these are subjective criteria. It is quite likely, and understandable, that the familiar knowledge (belief-system) of one's culture of origin will be chosen over modern science. Such choices, it is held, must be fully respected, as a matter of an ethical obligation of respect for persons and for cultures.

Given the technological products of modern science, humans now occupy a globe in which travel has become relatively easy. "Border-crossing" between and among cultures, both literally and figuratively, is a common phenomenon. Different cultures, formerly geographically isolated, which may have historically developed different knowledges, values, and ways of living, are increasingly coming to occupy the same geographical regions. This can lead to assimilation, in which the cultural "borders" gradually disappear. But it can also lead to cultural conflict, which may develop into domination, exploitation, and violence, and even to attempts at cultural genocide. This state of cultural antagonism is one of the most serious of the dynamic interactions facing global society, and may become catastrophically destructive. How is the problem of cultural conflict to be addressed?

In the post-modern world-view, and in cultural studies of science education, the solution is thought to require a radical change in the naturally human antagonistic response to cultural difference. An important goal of education, and *a fortiori*, of science education, on this view, is to bring about the appreciation and celebration of interpersonal difference. Two things are conflated, however: respect for persons, and respect for persons' beliefs. Respect for persons is an essential social ethical norm, a judgment that can be warranted by reference to inquiry into the well-being of persons in a social context. But this ethical norm does not require adopting a non-critical attitude toward the beliefs, practices, or knowledge assertions of those persons. Persons are to be treated with respect. In contrast, the actions, belief, and assertions of knowledge of all persons are to be subjected to ongoing critique, and continual testing, through modern scientific inquiry, for evidence of truth. Such critique is important if social problems are to be ameliorated; and, such critique is itself a form of respect for others as rational persons.[7]

Given the multi-logicality and multi-science commitments of CSSE curricula, students are likely to accept that making legitimate value judgments with respect to belief systems is not possible, and that efforts at evaluation are morally deplorable. This is a mistake. Comparative evaluative judgments of belief systems are possible, via scientific method (see Sect. 4.3).

Gellner identifies two approaches to the evaluation of socially accepted beliefs: re-endorsement theories and selector theories. Re-endorsement theorists "after profound reflection, reach the conclusion that all is well with [the] existing bank of beliefs, or at least with a substantial part of it, simply in virtue of it *being* the existing bank of beliefs" (Gellner 1974, p. 46). Gellner gives an example of a re-endorsement form of evaluation, built upon the principle of natural selection. The argument "could run as follows: beliefs only survive if true. Hence the bulk of time-tested beliefs of any society must be correct. Hence it is wrong to be doubtful of the whole bulk of local convictions. All in all, they must be sound" (Gellner 1974, p. 47). Re-endorsement theorists "claim to have found some reasons for supposing that current beliefs, simply in virtue of being part of the existing bank of ideas, are sound. No *outside* endorsement is required, they claim" (Gellner 1974, p. 47).

This is the reasoning that underlies the CSSE view of the assessment of claims to have knowledge. Gellner argues against such reasoning, and concludes that evaluation of the cognitive legitimacy of socially accepted banks of belief requires the selector theory approach. Selector theories:

> set up some *criterion*, some touchstone or sifter, which is to sort out the cognitive sheep from the goats. It is of the essence of this approach that the principle of selection claims to be independent of the current and local set of beliefs, to stand outside them and to be endowed with an authority external to that set (Gellner 1974, p. 47).

[7] On this issue of respectful disagreement see, among others, Siegel (1997).

Gellner give an example of a selector theory: “beliefs are sound in so far as they are arrived at by the methods of natural science, which consist of (let us say) accurate observation, and the acceptance of theories only if well-supported by such observations” (Gellner 1974, p.47). Gellner’s distinction captures the difference between the cultural studies mode of evaluation of bodies of belief and the evaluation of bodies of belief characteristic of modern science.

4.2.3 The “Sciences” of Culturally Distinct Peoples

The CSSE thesis of “multi-cultural science“, or, alternatively, “multi-science”, is problematic. One problem with adopting this re-construction of science is that the move is thoroughly destructive of the communicative usefulness of the term ‘science’. This is because when a term is given an extension that includes radically different and mutually exclusive activities and things/events in the world, the term loses its meaning. It can no longer serve to refer to some *particular sort* of thing/event, nor can it indicate a particular meaning to other persons. The term loses its intellectual function of marking a particular concept that has a place in a logically connected network of meanings.

It might be argued that this is a mere inconvenience, easily remedied by systematically qualifying the term ‘science’—e.g., to speak of “modern Eurocentric science” and contrast this science with any number of culturally specific sciences, e.g., indigenous Blackfoot science, or indigenous African science. But this misses the point. If “science” is the overarching linguistic/cultural category, its subcategories should share features in common that mark them as forms of the broader category of science. When there are fundamental differences in meaning of the subcategories, the meaning of the term ‘science’ is attenuated to the point of near vacuity. Once the extension of the term ‘science’ is accepted, the body of religious dogma of various Christian fundamentalists can legitimately be called “creation science”, even though there is nothing in the methods of inquiry that qualifies this body of religious belief as a science.

The term ‘science’ has long served as a technical term with a specific meaning. With the cultural studies of science education’s revision of the meaning, we now have two mutually exclusive alternative meanings, the standard meaning, and the cultural studies of science education meaning. The CSSE reconceptualization brings to the term ‘science’ an indefinitely large number of possible specific meanings. The term ‘science’ has been associated in the cultural studies usage with so many fundamentally different specific meanings that, to be useful at all, the term must be qualified. I will use the term ‘modern science’ to mark one conception of science, and the term ‘post-modern science’ to mark the indefinitely ambiguous re-conception developed in the cultural studies of science education field. The same point applies to the term ‘knowledge’; it is necessary to distinguish “modern scientific knowledge” from other forms of “knowledge” that are claimed, e.g., beliefs one accepts on the strength of dreams or scriptures, etc..

The CSSE re-construction, along with the adoption of a re-endorsement approach to evaluation of cultural beliefs, brings an evaluative relativism to the classic demarcation question in the philosophy of science. The demarcation question asks, by what criteria is genuine science to be distinguished from pseudo-science, from non-science, and from just plain nonsense? With the cultural studies conceptual innovation of multi-science, and more recently, multi-logic, the demarcation question is abandoned. In the cultural studies of science education, there are no criteria that allow the demarcation of modern scientific inquiry and knowledge about the dynamic causal inter-relations in the world from culturally accepted belief-systems that are inconsistent with modern science.

4.2.3.1 Indigenous Knowledges

Modern science, which is often said to have begun in Europe, (a view which disregards the myriad outside cultural influences on European cultural development) is considered in the cultural studies of science education to be a form of thinking that is deeply alien to persons of non-Western cultural origin. This diverse group includes all indigenous peoples,[8] and all persons of a non-European, non-Caucasian ancestry. It includes even "indigenous" persons and persons of non-Western ancestry who were born, raised, live and/or work in Western cultures. (See McCarthy 2014, p. 1938–1946.)

This is the thesis of cognitive essentialism. The assumption of this thesis is that human beings are *essentially* different, constitutionally different, from one another, in many ways, but in particular with respect to cognition and affect. There are thought to be "different ways of knowing" that are characteristic of distinct subclasses of the general biological category of *homo sapiens*. In the cultural studies view, the cognitive/affective differences are not merely culturally learned, and thus familiar, ways of thinking, feeling and valuing. These differences are genetically inherited, due to the long-standing cultural isolation of certain peoples. But this is a belief that is not warranted by modern science.

The thesis is, moreover, morally odious. The practical consequences of widespread adoption of and action on the thesis would be harmful, in major respects, to those persons deemed to be culturally and/or constitutionally ill-suited to the study of modern science. The science education offered to non-Caucasian persons would be limited by the perceived need to provide a culturally relevant curriculum, one that incorporates the culturally accepted beliefs—the "knowledge"—of each person's culture. This would have the further effect of denying to non-Caucasian persons equitable access to participation in science-based economic and cultural opportunities. The differentiation of science education curriculum would also likely

[8] The meaning of the term 'indigenous' is conveniently left vague, so much so that the term can be applied to virtually any group of people. The connotation is that indigenous peoples somehow belong to a particular geographical area, by virtue of having occupied that area in relative isolation, from time immemorial.

have deleterious effects on the self-conception of those who arset out their view succinctlye provided with "special" science education. The "multi-science" curriculum, promulgated as a special benefit, designed to assist the non-Caucasian student to understand and to be able to function within the constraints of "Western" modern science, is actually a particularly detrimental form of crypto-racism.

But it is clear that this is the position generally accepted by scholars in the cultural studies of science education field. For example, Elmesky (2011) takes it as given that persons of African ancestry, even those whose families have been long resident in cultures advanced in the practice of modern science, are alienated on a fundamental level from the patterns of thinking that characterize modern science.[9]

In *Theory of African Metaphysics,* Nichodemus provides details about the supposed "African" way of knowing. It is inconsistent with modern science. The author focuses considerable attention on the African commitment to the principle of causation. And gives a chilling example:

> In the African context, when the African asserts that the witch has killed her (the African) child what she is merely asserting is that the death of her child is an effect traceable to a cause in this case, the witch. The African understands that there must have been contact between her child and the witch. This contact is believed to be metaphysical. Among Africans, it is widely believed that the witch makes her contact by the help of an "invisible" rope…only the 'gifted' or the 'seers' can see this invisible rope used by witches. (Nicodemus 2013, p. 71.)

Nichodemus quotes Omoregbe (1990), to generalize the African causal principle: "There is no action without a cause, and the cause is always an agent or some agents utilizing some forces" Nichodemus 2013, p. 108). African philosophy involves the rejection of modern science. It is, she writes,

> a fundamental error of modern science, which is at the basis of modern medicine to assume that it has a comprehensive grasp of all that there is in reality, so it can state that whatever is not analyzable and explicable by its standards is not real or does not exist. (Nichodemus 2013, p. 109).

The African healer is reported to have access to important other ways of knowing, that go beyond the evidence of the sensory mode, and into the clairvoyant mode, where telepathy, clairvoyance and precognition are the principal means of divination. (Nichodemus 2013, p. 110). The author's use of the term 'African' makes it clear that every person native to the continent of Africa, who is raised in a traditional community, is taken to share the same cognitive stance.[10]

It is asserted that the incompatibility of modern science with the ways of thinking, being and doing of Indigenous peoples is so severe that to teach modern science to these peoples can constitute a form of intellectual colonialism. "[I]n many educational settings where Western modern science is taught, it is taught at the expense of indigenous science, which may precipitate charges of epistemological hegemony and cultural imperialism" (Snively and Corsiglia 2001, p. 7). Avoiding such charges

---

[9] For similar views, see Meyer and Crawford (2011), Ogawa (1995 and 1998), Roth (2009), Sefa Dei (2011) and Ritskes (2011).

[10] See also Metallic (2009).

while teaching modern science would be difficult, since Snively and Corsiglia follow Ogawa's (1995) view that "every culture has its own science", which is the culture's indigenous science (Snively and Corsiglia 2001, p. 7). I will examine below several representative examples of the belief-systems of Indigenous peoples, in the process of revealing the inconsistency of those belief systems with the knowledge resulting from methods of modern scientific inquiry.

Pavlik (2014) provides a thorough explication of the orthodox traditional cultural belief system of the Navaho people. His account, he states, is vouchsafed by Navaho traditionalists, and arises from Pavlik's 19 years of immersion in the Navaho culture, as teacher and student and participant. The orthodox traditional Navaho knowledge system, according to Pavlik, derives from a time before contact with outside cultural forces and Judeo-Christian religions. Drawing on early anthropological research, Pavlik writes that "It was a time when the Navaho people followed only the teachings of the 'Holy People', the *Yeis*. It was a time when they saw themselves intimately connected to, and part of, their sacred land and the other living beings with which they shared that land" (Pavlik 2014, p. 7).

Pavlik describes his work as "a study in the traditional [ecological] knowledge (TEK) of the Navaho people…how they viewed the natural world, their relation with the Animal People, and very specifically, with carnivores or predators" (Pavlik 2014, p.15). Pavlik quotes Berkes' (1999) definition of TEK; it is the "'cumulative body of knowledge, practice, and belief, evolving by adaptive processes and handed down through generations by cultural transmission, about the relationship of living beings (including humans) with one another and their environment" (Berkes 1999, p. 8, quoted in Pavlik 2014, p. 15). Pavlik distinguishes the traditional Native American relationship with all living things from that of western society: "Unlike western society, whose relationship with all life is based on competition and exploitation, the tribal relationship with all life—including the Animal People—was based on cooperation and reciprocal exchange" (Pavlik 2014, p. 15).

According to Pavlik, Navaho TEK has two forms: "the sacred (spiritual) knowledge handed down to them through the creation stories, and the experiential knowledge acquired through centuries of observation, inventiveness, and practice" (Pavlik 2014, p. 16). The creation stories are attended by a strong emotional component, which gives rise to the Navaho ethical system. Pavlik writes that TEK is gaining attention in western society, but that "[i]n general, the western scientific community continues to dismiss or disparage indigenous wisdom"(Pavlik 2014, p. 16). This rejection of TEK by western scientists occurs "because it is often not 'testable' in the scientific sense"(Pavlik 2014, p.17), and because "western science steadfastly tends to not take seriously any spiritual knowledge—the foundation of TEK." (Pavlik 2014, p.17).

Pavlik asserts that the Navaho have always known what is just now being discovered by modern science in the field of cognitive ethology, that animals have emotions and thoughts. The traditional knowledge of cognitive ethology, though, differs from that of modern science. "The fact that Navaho TEK stems from the sacred creation stories—from the spiritual realm—distinguishes it from mainstream cognitive ethology that accepts only a scientific evolutionary cause for animal behavior." (Pavlik 2014, p. 19).

It is clear, from Pavlik's account of TEK, and from the traditional stories and beliefs collected and discussed in the text, that TEK is based upon a tradition of divinely given stories, passed down through the generations. These sacred stories were used to provide interpretations of the meanings of the relations of the Navaho with the world they experienced. This store of divinely given statements stands as the set of foundational, indisputable statements, which are believed to constitute a foundation that justifies further knowledge claims. (See also Ritskes (2011) on the inclusion of Indigenous spirituality in science education.)

Deloria sets out the Native American world-view in great detail (Deloria 2002, 1997), and stresses the Native American concept of "power", as a spiritual living energy that pervades the universe. Pavlik (2014) follows Deloria in this, writing "The Navahos have long known that the universe is spiritually alive. *Everything* is a living breathing, spiritual entity. Every mountain and river, for example, possesses a spiritual essence" (Pavlik 2014, p. 45). Moreover, "The Navahos also know that there are wholly spiritual beings that reside at these places and protect them. The Navahos refer to these energetic entities as the *Yeis*, or the Holy People" (Pavlik 2014, p. 460).

It should be clear that dogmatic acceptance of traditional spiritual beliefs, derived from stories taken to be sacred, has nothing in common with the methodological norms of modern science. The case is the same as for the current fundamentalist Christian beliefs in young earth creationism. In each case, the belief system is religious dogma, not scientific knowledge. If scientific knowledge is understood as a set of statements that is well-warranted by evidence acquired via a rigorous process of experimental inquiry (as I shall argue in Part III that it should be), then the traditional spiritual beliefs that largely comprise TEK do not count as scientific knowledge.

The mixing together of the immutable doctrines of religious belief systems with the fallible results of modern scientific inquiry, held subject to continuous critical examination and testing, creates a serious problem of intellectual coherence, because the two world-views, the scientific and the religious, are incompatible in fundamental respects.

Mahner and Bunge (1996) argue that science and religion are factually, methodologically, attitudinally, ethically, and metaphysically incompatible, and that science education and religious education are, as a corollary, incompatible. Mahner and Bunge's analysis provides clear criteria that separate the religious from the scientific. Even a cursory inspection of the contents of what are said in CSSE circles to be systems of "indigenous science" reveals that the belief systems in question are religious, and bear no relation to science. "[I]f one is concerned with the education of the public, then the teaching of the religious attitude and value system can only have detrimental effects for adopting a comprehensive scientific outlook or critical attitude" (Mahner and Bunge 1996, p.118).

Peat, in *Blackfoot Physics: A Journey into the Native American Universe* (2005) asserts that modern science deals only with what can be measured and treated mathematically, and thus excludes from reality such things as love, beauty and mystical ecstasy, and is therefore problematic. Peat asserts that there is an alternative way of thinking about the world, an indigenous science that is distinctly different from modern science. Peat states: “Indigenous science does not need to explain itself to anyone. It has no need to compare or authenticate itself against the standard of Western science” (Peat 2005, p. 241). In comparing the “two sciences”, Peat argues first that modern science does not live up to its own standards. Peat notes, correctly, that modern science is supposed to be guided and arbitrated by nature, but then asserts, incorrectly, that “scientific theory is supposed to stand or fall according to the results of a single critical experiment” (Peat 2005, p. 242).

Recounting the Pons and Fleischman experimental efforts to demonstrate cold fusion, and the negative reaction of the scientific community to their claims to have done so, Peat asserts that “far from all experiments [are] reproducible…it is well known that some individuals can get a particular experiment to work, while others never will” (p. 246). Peat concludes, “Hence, the very basis of science, its objective, repeatable, quantitative observations and experiments, is an unattainable ideal, for the way scientists are able to design experiments and carry them out is influenced in so many subtle ways by their feelings and sensitivity to the complex universe around them” (Peat 2005, p. 246).

Peat’s implication is that certain persons are more attuned to the universe, in a direct, personal, spiritual way, and this special relation enables such persons to achieve experimental results that are not possible for ordinary persons. It is Peat’s view that modern science is a cultural product of the West, and as such is merely one human response to the world, one science among many other sciences that are equally legitimate, or perhaps more legitimate. “The fact is that Western science, and the way we pursue it, is a product of our value-system and our worldview. Societies with other values and other worldviews may choose to carry out their science in radically different ways” (Peat 2005, p. 248). But, *contra* Peat, the development of modern science is in fact a global accomplishment, both now and in its historical development. To treat modern science as if it were an ineluctably culture-based belief system, just one among many other equally valuable “ways of knowing”, is not justified.

In *Blackfoot Physics*, Peat is explicit about the nature of Blackfoot cultural belief system, and makes it clear that that belief system is fundamentally inconsistent with the belief system warranted by modern scientific inquiry. Peat also makes it clear that the methods of fixing belief in Blackfoot culture are incompatible with the method of modern scientific inquiry. Moreover, according to Peat, the Blackfoot epistemological model and worldview is representative of all indigenous belief systems. Peat sets out 29 major ways that Indigenous belief systems and methods differ from those of modern science. A few quotations with respect to key differences will have to suffice to indicate the incompatibility that Peat quite effectively establishes.

Objectivity “If objectivity implies the ability to abstract and distance oneself from nature, then this is definitely missing within Indigenous science. In its place, however, stand consistency, integration, harmony and balance” (Peat 2005, p. 255).

According to Peat, in Native science, "stress is laid upon direct subjective experience and upon closeness to nature. The powers, energies, and spirits of the world are personified to the extent that it is possible to enter into direct relationship with these elements and negotiate pacts, compacts and ways of living together with them" (Peat 2005, p. 255).

Prediction "The concept of what, within Western science, would be called prediction is profoundly different within a metaphysics that is not based upon the notion of causality….There is a sense in which dreams can have a predictive quality…the dreamer is not confined to a single present but can move back and forth along the curve of time" (Peat 2005, p. 255).

Experiment Peat states: "Analogies can be drawn between…contemplative practices of the East and the observational/experimental approaches of Indigenous science. So, while Indigenous science does not employ experiment in the Western scientific sense, it does employ a disciplined approach to merging horizons with the inner reality of the world and revealing its different levels of process" (Peat 2005, p.252).

Observation "For observations to be of use they must be recorded and passed on…[in Indigenous cultures] knowledge is generally passed on through markings on rocks, mnemonics, songs, ceremonies, practices, artifacts and such things as earthworks. In particular, much knowledge about the world is enfolded within traditional stories" (Peat 2005, p. 250).

Control "Although it could not be said to be a form of control in the Western sense of the word, Indigenous peoples are also able to make use of certain processes in order to bring about desired effects … Examples include the ability to heal and to extract diseases from the body, or to negotiate with clouds in order to produce rain. Songs could also be thought of as processes, or scientific instruments, that bring about certain effects" (Peat 2005, p. 254).

Instrumentation In Indigenous science "knowledge goes beyond what can be apprehended through the normal senses…ceremonies and practices such as fasting, acts of sacrifice, dancing, ingestion of various preparations, dreams and visions all serve to refine the instruments of perception and allow direct contact with extended realms of reality" (Peat 2005, p. 260). "Indigenous science also makes use of technological instruments. For example, the Cherokee people utilize crystals in many different ways. One is in the preparation of medicine, where sunlight is guided through the crystal and onto the preparation to potentiate its power" (Peat 2005, p. 260).

Truth According to Peat, "Western science seeks ultimate truth, for it believes in a rational universe that can be understood by experimentation and reason….Truth in Native science is of a very different order. Truths…depend on tradition and social and spiritual sanctions. Dreams and visions are systems of validation. Truth is contained within origin and migration stories, songs and ceremonies…the source of truth is found in nature and in the direct experience of individuals through dreams and visions; conversations with rocks, trees, and animals; and patient observation of the world around them" (Peat 2005, p. 265).

Spirit and Energies "The animation of nature and the energies or spirits that reside in plants, animals, rocks and trees are characteristic of Native science. The acknowledgement of powers and the renewal of alliances through a variety of ceremonies also play a key role in Native Science. This notion of spirit, or numinous energy, is missing in Western science" (Peat 2005, p. 271).

Observer-Created Reality "The transforming, animating energies of Western science are strictly impersonal and move according to the objective laws of physics. These laws are pictured as being totally indifferent to human wishes and desires" (Peat 2005, p. 285). "In contrast, the Indigenous world is alive….Far from being indifferent to the existence of humans, it is possible for The People to negotiate with the world of spirits and form alliances with the powers that animate the universe. As an example, when drought occurs The People may carry out a rain dance." (Peat 2005, p. 285).

In this uncommonly detailed account, Peat makes it abundantly clear that the indigenous belief systems he describes are fundamentally inconsistent with modern science. The illusion of compatibility is created by nothing more than an extended trick of verbal magic. The terms that carry a specific technical meaning in modern science are lifted from the modern scientific context, and are applied to certain elements of the traditional Indigenous systems of belief and methods of fixing belief. But, in the new context, the borrowed terms no longer *mean* what they meant in the original context. So, for example, the meaning of the term 'observation' in the context of modern experimental inquiry entails empirical observations--persons noting events in the natural world, and especially, the events that occur following intentional interaction of person and environment. In the context of indigenous culture, the term 'observation' is used to include experiences that are had during sleep (dreams) or in altered states of consciousness (visions). This difference in meaning is glossed over; it is stated that both ways of fixing belief employ "observation", therefore both systems are equivalent in this respect. But, clearly, both systems in actuality rely upon quite different forms of practice.[11] The missing feature in all of the proposed "alternative sciences" is the scientific method itself.

Aikenhead and Ogawa set out "three diverse cultural ways of understanding nature: an Indigenous way…a neo-indigenous way…and a Euro-American scientific way (Aikenhead & Ogawa 2007, p. 539). The intent is to "better represent each culture's collective, yet heterogeneous, worldview, metaphysics, epistemology, and values" They also attempt to show that Indigenous knowledge systems share important features with scientific knowledge systems, namely, "empiricism, rationality, and dynamic evolution" (Aikenhead and Ogawa 2007, p.539).

[11] For further explanations of the nature of "Indigenous science", and calls for the inclusion of such science in science education, see: Aikenhead (2001), Boyer (2010), Cajete (2000), Deloria (1997, 2002), Langdon (2009), Medin and Bang 2014), Meyer and Crawford (2011), Ogawa (1995, 1998), and Snively and Corsiglia (2001). In 2017 there is a proposal before the U.S. National Association for Research in Science Teaching (NARST) to include Traditional Ecological Knowledge as a research strand in the organization.

Aikenhead and Ogawa define the term 'science' as: "*a rational empirically based way of knowing nature that yields, in part, descriptions and explanations of nature"* (Aikenhead and Ogawa 2007, p. 544). They follow Elkana (1971), in defining rationality as culturally relative, and explicitly reject any sense of universalist rationality. They take *perceiving* to mean "both the process of constructing what is perceived to be reality through the participation of a group of people, and their resultant mental constructions of reality" (Aikenhead and Ogawa 2007, p. 543). Further, they adopt "a multi-science perspective" (Aikenhead and Ogawa 2007, p. 544).[12]

In modern scientific inquiry, suggestions as to possible meanings can arise from any source, even from a dream or a trance. But, regardless of their origin, it is *de rigueur* in modern science that suggested meanings be subjected to a continual process of empirical, experimental testing, by a global community of scientists. The scientific testing of the suggested meanings is the key characteristic distinguishing science from fanciful non-critical belief.

Shahjahan and Haverkos present Indigenous systems of knowledge as instances of "spiritual epistemology", and argue that the academy unjustly takes knowledge to require a Eurocentric secular epistemology. The academy thus serves Western colonialism, unjustly fencing out all spiritually based systems of knowledge. "In the secular epistemological vision, rationality, anthropocentrism, and empiricism are lauded over many other ways of knowing (e.g., emotions intuition, metaphysical, and ancestral connections) (Shahjahan and Haverkos 2011, p. 377). Shahjahan and Haverkos argue that the dominant secular epistemology must be resisted, that the academy should accept spiritual epistemologies, and the "other" ways of knowing the world, as equal to modern naturalistic science in value. Ritskes goes a bit further: "In the Western academy there is currently no use for this kind of knowledge which flies in the face of everything that it stands for" (2011, p. 417.) While this should be true, it is apparently not true in the CSSE conception of science education.

Those who call for the inclusion of Indigenous "ways of knowing" in science education classrooms would seem to be either uninformed as to the actual substance of the body of belief that they extoll, or lacking in an understanding of the distinctive character of scientific inquiry and of scientific knowledge. But, it is also possible that advocates of inclusion of Indigenous "science" in science education are indeed aware of the difference, but for some reason are antagonistic to modern science and seek to "re-enchant" the world with the introduction of ancient, and still occurrent, superstitions.[13] In any case, the results of the infiltration of science education by this and other forms of anti-science can only have deleterious effects on the already poor public understanding of scientific knowledge, and the public dispositions to use scientific knowledge in addressing critical social problems.

Critical social problems are undeniably present. The problem of global climate change is one example, but it is drawn from a large array of such problems. That

[12] See also Aikenhead (2014).

[13] See Griffin 1988a, b.

global warming is occurring, and that it is one of the consequences of human interaction with the environing conditions, is well established by the community of modern science.[14] Given the vast number of causal conditions, among which one must include global human activities, that together constitute the conditions of occurrence of global warming, there is a pressing need to employ scientific knowledge of the dynamics of interaction in the natural world so that successful mitigation practices might be begun.

But, a shared societal consensus on the necessity of modern scientific knowledge is difficult to achieve, and becomes more difficult to the extent that science educators teach that traditional indigenous belief systems, and other alternate ways of knowing, are the cognitive equivalent of modern scientific knowledge. When, in the U.S., politicians facing drought conditions lead public rain dances, or public prayers, the causal conditions for climate catastrophe are enhanced.

4.2.3.2 Seeking Alternatives to the Scientific Way of Knowing

The claim that Indigenous cultural systems of belief are acceptable as alternative forms of knowledge for the science classroom is, on inspection, implausible. But additionally various other ways of knowing, also in opposition to the way of modern scientific inquiry, are commonly promoted in the cultural studies of science literature.

One prominent thesis, developed in the field of feminist epistemology, is that there are natural female ways of knowing, which are different in kind from the ways of knowing of males. Science, on this view, having been (largely) developed by male persons, is well fitted to the thinking patterns of males but is significantly less well suited to female persons. Science education, it is concluded, should, for the sake of social justice, incorporate the distinctive "women's ways of knowing". But to do so would require a radical reconstruction of the practices and theses of modern science.[15]

It is sometimes claimed that modern scientific inquiry is fundamentally alien to *all* persons, which is thought to explain why it is difficult for all persons to learn modern science; this thesis is sometimes used to justify calls for the re-enchantment of the world. Curiously, this is the least objectionable position. Peirce (1986/1878) famously noted that, for most people, it is not true belief that is actually desired. What is desired is simply the *fixation* of belief, which puts to an end the onerous process of thinking about beliefs and evaluating them with respect to the evidence of their being true. Wolpert, in *The Unnatural Nature of Science* (1992), argues that the way of thinking of modern science does not come naturally to people. To acquire the way of scientific thinking, an extensive period of science education is required by all. It is to be expected that to become adept in scientific thinking is difficult. But

[14] See Cook et al. 2016.

[15] For affirmations of this view, see Harding (1996) and Brickhouse (2001); for critiques of it, see Landau (2008) and McCarthy (2014).

this does not mean that the meaning of science should be changed to include within "science" the ordinary human approaches to fixing belief. It instead underscores the need for a science education that engages the students intellectually, and that helps them to develop a disposition to think scientifically.

The charge of "scientism"is frequently brought against modern scientific inquiry. The term 'scientism' can be defined as the belief that the methods and norms of modern science should be brought to bear on a wide range of problem situations, as the only legitimate means of attaining genuine knowledge of the real thing/events that constitute the problem. It is held that only through modern scientific inquiry that understanding of the dynamics of the problem situation can be attained. And it is only through modern scientific inquiry that effective means of ameliorating the situation can be devised. On this view, modern scientific inquiry should be applied to social, moral, political, economic and educational policy, in order to provide the best possible knowledge of such problems.

But scientism is also widely understood as a deplorable over-reaching of modern science, as an inappropriate intrusion of science into humanistic realms. Modern scientific inquiry is considered inappropriate, ineffective, and, indeed, strongly counterproductive when applied to the domain of human concerns. Smith (2013), for example, condemns scientism on the grounds that it conflicts with and undermines the ancient wisdom of religious revelations. "It is no wonder…that this presumed scientific wisdom runs aground when it comes to the understanding of man himself; that it has in fact shown itself categorically incapable of accounting for even the most rudimentary act of cognitive sense perception, let alone for the higher modes of sensory and intellective knowing" (Smith 2013, p. 10).[16] Rescher concludes "no matter how far we push science forward along the physical, chemical, biological, and psychological fronts, there are issues about humanity and its works that will remain intractable by scientific means … because these issues lie outside it" (Rescher 1999, p. 244–245).

Williams states "that scientism entails a metaphysical commitment to a naturalist, reductive, or emergent materialism and tries to define science in a way that includes not only a commitment to empirical methods, but also to this particular metaphysics….the propriety of any method is evaluated primarily in terms of whether it deals with the world as if it really is as naturalist materialist metaphysics claims it is" (Williams 2015, pp. 3,4).

Williams acknowledges that the methods of naturalistic and materialistic science "seem relatively compatible with the natural world" (Williams 2015, p. 8). Williams believes a problem arises, though, when such methods are applied to the human world. To do so would be to explain the fundamentals of human being "in terms of things outside of themselves, and to explain them in that way is to destroy them" (Williams 2015, p. 8). What Williams fears will be lost, it seems, is the conception of a uniquely human spirituality, that is outside the bounds of the natural materialistic world.

---

[16] See also Nagel (2012) and Sorell (1994).

But, the general method of modern scientific inquiry is the only way of providing the strong warrant for the truth of a proposition that is necessary for knowledge. Because human beings are themselves dynamic, interactive thing/events in the world, a part of the natural world, as are the social/cultural products of human interaction, a genuine knowledge of their interactivities is possible via scientific inquiry. There is no alternative way to acquire knowledge about the world. Bunge conceives scientism as "methodological realism", the thesis that "[t]he best strategy for understanding the world is the scientific method" (2006, p. 30), and links scientism to both scientific realism and materialism (2006, p. 280). This triad is the core of Bunge's *scientific hylorealism*, a position which, like Dewey's view of scientific inquiry, indicates the possibility of a science of ethics and social justice, generating knowledge in the sense of well-warranted assertibility.

4.2.4 Constructivism and Scientific Knowledge

Michael Devitt (2012) describes constructivism in this way: it is the thesis that "scientific entities are not independent but are somehow 'constructed' by the theories we have of them. This 'constructivism'has its roots in the philosophy of Kant and is extremely influential" (Devitt 2012, p. 101).[17] This ontological constructivism is widespread in education.[18] John Staver, a prominent science educator and constructivist, stated it as follows:

> …For constructivists, observations, objects, events, data, laws, and theory do not exist independently of observers. The lawful and certain nature of natural phenomena are properties of us, those who describe, not of nature, that is described. (Staver 1998, p.503)

Tobin and Tippins, in 1993, present constructivism as an epistemological thesis that has skeptical implications, but that does not deny that the world in all its interactions exists. "[T]he existence of a reality is acknowledged from the outset. What constructivism has to say about that reality, however is that we can only know about it in a personal and subjective way." (Tobin & Tippins 1993, p. 3). Tobin and Tippins give an example: they acknowledge that gravity exists, but assert that human beings can only come to know about what gravity *is* by individual personal experience of the phenomenon, supplemented by a social process of negotiation of meaning. Through social negotiation, they continue, "agreement is reached within our social system that the concept of gravity has numerous verifiable properties. We construct a model of gravity that is viable in that the model fits experience" (Tobin and Tippins 1993, p. 3).

But Tobin and Tippins explicitly deny that the model can be considered "to be an absolute truth"(Tobin and Tippins 1993, p. 4). They do not make clear what the conceptual distinction might be between "absolute truth" and truth *simpliciter*, truth

[17] See also Devitt (1991)

[18] For examples and discussion, see Matthews (2015, chap. 8).

as the correspondence of statements of interactions in the world with actual interactions in the world. It is possible that they use the term 'absolute truth' to refer to statements claimed to be indubitably true. But no modern scientist makes claims about scientific truth in the sense of indubitable truth, because scientific knowledge is understood as fallible, and only to be held subject to further evidence that brings the knowledge claim into doubt.

In Tobin and Tippins' view, knowledge begins with a subjective interaction, not with the real world, but with our constructions of the world. "Our constructions are constrained by experiences, which comprise subjective interactions with the real world as we have constructed it" (p. 4). If the term 'constructions' denotes imaginative conjectures about interactive events in world, this is a reasonable account of an early phase of every modern scientific inquiry. Our conjectures are imaginative. But, Tobin and Tippins seem not to notice that our experiences, i.e., our interactions in the world, are fully objective. That is so because the organism, including all its internal interactions, is no less a real interactive thing/event than is an inorganic interactive thing/event. We develop conjectures about the world, and expectations about the effects of our interactions with the world. But what we interact with is the world *as it is*, not the world as we have "constructed" it imaginatively.

Given that our interactions are objective real events, we can learn about the world by taking actions based on our conjectures about the world. Should our expectations about the observable state of the world following those actions be disappointed, we have learned that something is wrong in our conjectures about the world.[19] The hypothesis has been put to the test, and has been disconfirmed. Disconfirmation, in Popper's view, is strong evidence that our "construction" is not right, that it is false, in that it does not correspond to the world.

But, what about evidence of a positive sort? What if after action guided by a hypothesis we do observe the state of the world we had expected? Given severe testing of the hypothesis, the failure to observe disconfirmation, according to Popper, provides corroboration for the hypothesis. Corroboration is a matter of the appraisal of the hypothesis, and is a matter of degree. A hypothesis can be judged to be highly corroborated, or less well corroborated, by a scientific inquiry process (Popper 2002, p. 264–265).

Tobin and Tippins continue: "Since there is no objective account of what gravity really is, we cannot tell whether our model for gravity gets closer and closer to an absolute reality…we can only know gravity in a personal, socially mediated way." Tobin and Tippins seem to be supposing that an objective account of the actual workings of gravity must be available, *independent of human inquiry*, to which the results of human inquiry can be compared for accuracy. Something like a teacher's answer book. Since, obviously, there is no such extra-human account – because accounts of thing/events are all of human origin – there is no possibility of comparing one's conjectured account of gravity, or any interaction, to some imaginary "given" extra-human account. Though some persons purport to have received

[19] Or, that something is wrong with our background assumptions, or our experimental procedures, or our instrumentation, etc..

authoritative extra-human accounts of the world from a putative divine source, the evidence for this is underwhelming.

But, there is no need for such a pre-existing account, since what we do have is the actual world with which to interact. Popper's account of the logic of scientific discovery allows for both the disconfirmation of theories, and for the corroboration of theories, through experimental inquiry. As long as one is willing to discard the conception of knowledge as entailing absolute certainty of truth, no problem arises. Through interaction, designed to subject hypotheses to severe testing, we have the resources needed to assess the claim that the judgments reached about the world are true.

It is true that, initially, prior to cognition, we *experience* our interactions in the world in a direct, and qualitative way. But this primary qualitative experience, because it *is* immediate (i.e., unmediated by thought) and qualitative, is not knowledge. Achieving knowledge requires considerable cognitive mediation. It requires well-tested processes of testing prospective beliefs via active experimental inquiry.

The practice of modern science does have a social aspect; scientific inquiry must be associated with a cultural milieu that supports the search for true belief about the world through experimental inquiry into the puzzles, the "problem situations" that arise. The scientific search for knowledge, for well-warranted beliefs about the world, requires a cultural commitment of resources to the maintenance of a community of scientists, who will be working collaboratively over an extended period of time on the development of theories about the world, and the experimental testing of those theories. Modern scientific knowledge is a set of well-warranted judgments that result from the collective and continuing social process of scientific inquiry.

Truth is conceived in the cultural studies of science education literature as a matter of viability, either in von Glaserfeld's sense of holding up in practice, or in the broader sense of being culturally accepted over long periods of time. But, the simple persistence of belief over time is not a reliable indicator of the probable truth of the belief. Conceiving truth as a matter of a correspondence between statements about the events of the world and the actual events of the world, scientific inquiry allows the development of a set of theoretical statements about the world that are well warranted to be true.

Tobin and Tippin's epistemological constructivism is deeply embedded in the cultural studies of science education field. It is this position that supports the acceptance of all culturally established[20] belief systems as equally legitimate knowledge. This leads to the conviction that all cultures have their own forms of science, and then to the notion that all cultural belief systems must be equally respected, and equally welcomed, and for some, equally affirmed in the science classroom.

[20] In the cultural studies of science education literature, the cut-off date for "long-standing" belief is never specified, leaving the notion empty. Moreover, the age of a set of beliefs is entirely irrelevant to the truth of the belief, and is equally irrelevant to the warrant of the belief to be true.

4.2.4.1 Social Justice and CSSE

It is difficult to see why anyone would seek to acquire knowledge, in the postmodern/cultural studies sense of the term. It is certainly *possible* to alter the meaning of the term 'knowledge', in such a way that any system of belief about the dynamic interactions of the world will count equally as knowledge. But what will have been gained?

Knowledge, if it is to be a goal worth pursuing, must be conceived as a coordinated set of judgments about the real dynamics of the natural physical and social world, judgments that are thorough enough, accurate enough, close enough to being fully true, that we can act effectively to achieve the individual and social ends we value. Should our knowledge of human social dynamics and human valuings ever become thorough enough, and true enough, it is possible that that social knowledge might allow us to effectively critique our valuings, as well as our beliefs. If so, we may manage to choose our ends wisely, so that our pursuing and achieving of immediate goals does not lead us to destroy the more essential values we eventually come to see.

Reforming our human-to-human inter-relationships, and our human inter-relationships with rest of nature, requires action, and action requires knowledge, in the modern scientific sense. Conferring the title of "knowledge" on every belief system, as a way of according respect to persons, is not a step in the right direction. The consequence of such a move is that we develop societies that pay no special heed to the scientific knowledge so far achieved, not even when making momentous and perhaps irreversible decisions about social action.

The solution to, or the amelioration of, the urgent social problem of global warming depends on scientific knowledge of the problem, the conditions of occurrence of the problem, and consequences to be expected from our actions, given its occurrence. The problem of global warming is but one of the many potentially disastrous consequences of past and current human action in the real world, which will interact with us, responding to our actions, as it must, regardless of our expectations, our wishes, or our regrets.

The social structure that has emerged in the democracy of the U.S. has brought into positions of power the sort of persons who, for reasons of ideology, or religious belief, of personal greed, of hubris, or of sheer ignorance, refuse to make use of the best scientific knowledge of the day as a basis for political/economic/social action. Those who have the least, in every global village, can be expected to be those who suffer first the ill effects of unmitigated global warming. Given this, the development and employment of modern scientific knowledge is a matter of social justice.

It would go too far to lay the blame for the scientific somnambulence of the populace solely on the schools and on science education. It would go too far, too, to blame this solely on the current popularity of a thesis which holds that genuine knowledge of the world dynamics is impossible, and that it is therefore only fair to confer upon every belief system, however generated, however likely or unlikely to be true, the title of knowledge, or better yet, science. But, the misrepresentation of the nature of modern science, and its distinctive cognitive value, in the course of science education, cannot have good consequences for the scientific literacy of a culture. It prepares the way for the acceptance of "alternative facts" and "alternative truths" in Donald Trump's presidential-advisory circles.

The cultural studies of science education theses appear to be motivated in large measure by misguided conceptions of social justice. The achievement of social justice is taken to require giving equal respect to all cultural systems of belief and methods of fixing belief. However, social reform, to be effective, requires a highly developed scientific knowledge, knowledge of the complex dynamic conditions that generate and maintain the pervasive systems of social injustice currently dominant across much of the world. Critical evaluation of the cognitive worth of conflicting systems of beliefs claimed to be knowledge is a necessary condition for the reform of the current situation of rampant social injustice.

Social justice should be conceived as a matter of actually achieving, in the real world, a just distribution of social goods and social opportunities, along with the freedom and ability to effectively pursue valued ends, through socially just means. In this sense, social justice is a critically important goal. But social justice is not achieved simply by asserting that equality exists, not even when that assertion is backed up by elaborate word magic. Re-conceiving scientific knowledge and scientific inquiry so as to be inclusive of any and all cultural belief systems, no matter how the system is achieved, no matter how inefficacious the supposed knowledge is, is not a means of actually achieving social justice.

Modern scientific knowledge is fundamentally different from other belief systems, in that the process of scientific inquiry provides a way of assessing the truth, in the sense of correspondence, of the beliefs about the world that science generates. A scientifically produced belief system is demonstrably more efficacious than other belief systems in facilitating successful interactions in the world, and progress toward the achievement of desired future states.

4.3 The Basics of Modern Science

A well-established body of scientific knowledge is a body of logically inter-related statements about the interactive dynamics of the natural world, which together constitute theoretical knowledge of the world. The theories, and the statements which comprise them, are understood to be true of the world, in the correspondence sense. The processes of interaction in the world, guided by theory, provide a continual testing of the truth of the scientific theory.

Well-established knowledge, understood in this sense, is a valuable outcome when achieved, and well worth the pursuing. It is the function of a body of knowledge to guide action in the world, in such a way as to solve problems set in and by the world, i.e., in the natural situations in which organic actions occur.

The process of scientific inquiry is the interactive process through which hypotheses, statements of possible interactivities, possible meanings of events, are generated, elaborated and tested by action in the world. The goal of scientific inquiry is to pursue true beliefs about the world. The continual social process of scientific inquiry leads to the progressive development of knowledge of the world.

If modern science cannot reach knowledge of an existing and operative set of dynamic interactions, and the probabilities thereof, then there is no point to doing modern science. There is little advantage to be gained by achieving a cultural consensus in beliefs about the world, if those beliefs are not well-warranted to be true of the world, in the correspondence sense. The only advantage in arriving at and maintaining a fixed belief system which is not well-warranted to be true of nature is the fostering of a feeling of solidarity, of community of belief. But false beliefs about the world are likely to lead at some point to actions in the world that fail miserably in achieving the desired goal.

The statements that are well-warranted by experimental scientific inquiry to be true may, on further scientific inquiry, be shown to be false. But, as part of the ongoing process of scientific inquiry, the early judgments of truth, though later falsified, are valuable. They set the stage for further inquiry. The continual process of testing the results of prior scientific inquiry leads to the continual correction of errors, and improvement over time of knowledge of the world.

Even true beliefs can lead to failure in action, when combined with false subsidiary statements, or unrecognized complications in the situation. Nevertheless, a set of mostly true beliefs will generally be better as a guide to action than a set of mostly false beliefs. It should also be stressed that scientific inquiry provides no guarantee that the resulting judgment about the world is true. All that can be provided is a strong warrant to believe that the judgment is true.

The epistemic goal of having true beliefs (correspondence sense) about the world is justified by its contribution to achieving valued end states of action. But, this practical consideration of the usefulness of scientifically generated belief should not be mistaken for the criterion of truth. The criterion that permits the assertion that a judgment is true is the scientific inquiry process itself.

4.3.1 Scientific Inquiry, Correspondence Theory of Truth, and Knowledge

Mario Bunge sets out an account of the scientific method, in general, of the meaning of 'scientific knowledge', and of the correspondence conception of truth regarding the world (Bunge 1967/1998). The scientific method, in Bunge's view, requires first, a problem situation, second, a more precise statement of the problem (p. 9), a set of hypotheses (guesses) as to the actual dynamic interactions constituting the problem, and a testing of the hypotheses, through deduction of some of the observable consequences of the hypotheses, and then action on the basis of the hypotheses, to test the agreement of the predicted results of the action with the actual results of the action.

Bunge's account of the scientific method (see Bunge 2006) is remarkably similar to that of John Dewey. That the two descriptions *are* similar is remarkable, given the prominence of long-standing misinterpretations of Dewey's philosophy, which take Dewey to have followed the subjectivism of William James, and/or the idealism of Hegel.[21]

The process of scientific inquiry leads to judgments about the interactions of the world. Judgments, as such, are always reached under conditions of uncertainty. What is desired, then, in addition to the judgment itself, is an assessment of the strength of the reasons to accept the judgment, tentatively, as true of the world. The process of inquiry itself provides such reasons. To the degree that the inquiry process is competent, the warrant for the truth of the judgment is strong. Assessing the quality of the inquiry process, clearly, is itself a matter of judgment. The ineluctability of human judging in inquiry is the reason that scientific conclusions must always be held tentatively, and are always in principle fallible. Dewey conceives knowledge as warranted assertibility, in this sense.

The lack of certainty in scientific inquiry does not affect the concept of truth. The pursuit of true belief about the dynamic interactions of the world, if truth is to be worth pursuing, requires a correspondence conception of truth. Vision presents the conception of truth as correspondence to the world in this way: "the truth of a proposition is constituted by a state of the world being such that were the proposition stated, it would state the world to be that way…" (Vision 2004, p. 87). On this view, a proposition is true if and only if the proposition refers to and accurately represents certain of the dynamic interrelationships of nature. This definition may seem to have a built-in circularity that makes it tautologically true, in so far as the term 'accurately' has the same meaning as 'truthfully'. But this is characteristic of definitional, analytic, statements. (Every dog is a member of the genus Canidae; the genus Canidae is the genus including all dogs.) What is required is more than a definition; what is required is a fuller account of the meaning of the concept of truth, and an operational definition, i.e., an account of what activities should be undertaken if a statement is to be rationally considered to be true.

The correspondence conception of truth is controversial, and often rejected. In *Nonsense on Stilts*, Pigliucci develops a strong indictment of pseudoscience and non-science masquerading as modern science. Yet, Pigiucci rejects the correspondence conception of truth, and links the correspondence conception to "scientism", by which Pigliucci means the intrusion of scientific inquiry into non-scientific questions. "[T]he entire scientistic attitude rests on a specific philosophical theory known as the 'correspondence theory of truth'"(Pigliucci 2010, p. 236). Pigliucci states that "the correspondence theory of truth essentially assumes that somehow we can step outside of what philosophers call our 'epistemic limitations'…and access a 'God's eye view' of things" (p. 237). However, Pigliucci accepts that it *is* possible to "show that the claims scientists make about science are in fact correct" (p. 264). But, what does the term 'correct' mean here, if not "true", in the correspondence sense of truth?

Truth, in the correspondence sense, is an absolute—a proposition is either true or false, and the world is the truth-maker. To attain "the truth, the whole truth, and

[21] See McCarthy 1996a, b, 2000, 2002, 2007a, b, and McCarthy and Sears 2000.

nothing but the truth", would be nice, but unfortunately is impossible. This is in part due to practical human limitations of time and effort, but, more importantly, it is impossible because attaining the "whole truth" about nature would require knowing every possible interactive event in nature. And this is logically impossible, because the set of all possible interactions is infinite, since every concatenation of actual or possible interactions, past, present and future, must be accurately represented.

The key to resolving this conundrum is to conceive of an all-true belief-system as a goal of inquiry. As a goal, it is an ideal, in the sense that it is a desirable and desired future state of affairs, not currently present, toward which we choose to work. If it were not humanly possible to even assess our progress toward that goal, the goal should be revised and/or rejected. The relevant question then is: Is there a way that a human being can assess the correspondence truth of a proposition, or of a theory? The answer to this question, I will argue, is "Yes."

But, how? In what sense? By what method? The Deweyan conception of experimental inquiry sets out a means to pursue the goal of a belief system that is increasingly true in the correspondence sense of the term 'true'. Dewey raises, and responds to, the question: "What is the experience in which the survey of both idea and existence is made and their agreement recognized?" (Dewey 1907, p. 79). Dewey presents the standard conundrum: in any experience, either both idea and fact are present, or only one, the idea *or* the fact, is present in experience. If 1: both fact and idea are present, no comparison of the two is necessary, for the facts are there in *propria persona*. If 2: only ideas are present, there can be no comparison, by definition. And if 3: only facts are present in experience, a comparison of idea and fact to check their agreement, their correspondence, is both impossible and unnecessary. This analysis would seem to be sufficient grounds for rejecting the correspondence conception of truth.

Dewey offers a solution to the apparently inescapable dilemma. But, it is a hard one to accept. The solution is that one must reject, completely, the metaphysical position of dualism. Dualism is the notion that there is one sort of thing called an "idea", which belongs to a "mental" realm, and another sort of thing, called a "fact," which belongs to a material realm. It is the assumption of dualism that leaves the correspondence conception of truth seeming untenable.

Dewey argues that having an idea is an existing occurrent thing/event, an interactive happening between a *human* thing/event and other, *non-human*, thing/events, in a situation. Both the idea and the fact of the matter are equally present in a situation of scientific inquiry, and thus can readily be compared. But, why would one do so? Why even form ideas, if, when one is fully immersed in the factual situation, the agreement or disagreement of idea and world is obvious?

One forms ideas because one's present situation is problematic. A necessary condition of a situation being "problematic" is that a person in the situation has a goal, an end-in-view, a future state of affairs that is desired, but that is not actually present, not currently existent. Action must be taken to bring about the desired future state (unless one chooses to wait for the chance occurrence of the desired state, or to hope for the action of others). If, given the person's history, and thus the person's present (physical) cognitive state, the course of action needed is clear, then no thinking process is needed; one simply acts on one's knowledge. What makes a situation problematic is that, in it, the person's current knowledge has proven to be inadequate. The person sees no clear connection between: the present situation; his or her action; and the occurrence of the desired situation. The person cannot effectively act, and so must stop, and think.

In such a situation, i.e., a situation requiring the activity of thinking to guide one's future action, the conception of correspondence truth makes sense. One has a present engagement with the problematic situation, open to inspection. One develops an idea, which is a potentially useful plan of action. An idea is an organismic state, a representation, which has two parts: (a) what is thought to be the nature of the problematic situation; and, (b) what is thought to be the active interventions that will change the existing situation, over time, into the desired situation.

Over the period of time while one acts guided by the idea, one is, clearly, fully present, physically/cognitively, in the developing situation. And one is fully present in the situation *that results* from one's acting. The idea one has formed can thus be tested through one's action. The idea leads one to expect a new situation of a particular sort to occur as an effect of certain actions taken under certain conditions.

Following action, one is in a position to compare (a) one's idea of the dynamic interactive relations constituting the problem situation to (b) the results achieved through the actions that are based on that idea. The result expected is compared to the result that occurs. If the two are different, there is something wrong, and the inquiry should continue.

For example, suppose one is lost in the woods, and desires not to be lost. One examines the current situation in light of one's existing knowledge, and develops an idea, a course of action thought likely to resolve the problem, to get one out of the woods. One acts, to test the truth of the idea, and discovers through action whether or not one's idea was adequate to solve the problem. If one succeeds, there is reason to think that one's idea of the environment, of one's position in it, and of the actions that will take one from the present situation to the desired situation, was true, in the correspondence sense. It is possible that the idea was false, and one just experienced epistemic luck. Because epistemic luck is always a possibility, genuine scientific inquiry must be a continual process, undertaken by an extensive community of inquirers. Given this, the epistemic luck, if a factor, is likely to be eventually discovered.

This is the basic structure of scientific inquiry. One faces a problem, a puzzle of some sort. In light of one's knowledge (best current theories), one forms an idea, a hypothesis, i.e., "If the dynamic relations constituting the situation *are* as I now *think* them to be, then, if certain actions are taken, the resulting situation *will be* the one I predict will occur". One acts on the hypothesis, and discovers whether or not the hypothesis (the idea about the consequences of particular actions in the particular situation) agrees with, i.e., corresponds to, the actually observed consequences that result from action in the problem situation. New evidence is thereby generated about the agreement or disagreement of idea and world. As a result of experimental reflection and action, an advance toward the epistemic goal of true belief has been made, and new knowledge has been acquired.

The *dis*agreement of the hypothesis, in some respects, with the situation in question, is the usual result. This result leads to a re-thinking of the nature of the actual dynamic interactions of the situation. A new or revised hypothesis (idea) is formulated, and one acts to test the new hypothesis. The process of experimental inquiry is repeated again and again by a large community of inquirers who are acting, as a practical necessity, in a social and cultural framework that supports the scientific inquiry process. Over time, a body of established scientific knowledge is developed.

It is the ongoing process of scientific inquiry that stands as the warrant, the justification, of the claim that the belief-system built up over time counts as genuine knowledge. For the sake of clarity, Dewey uses the new term 'warranted assertion' in place of the customary but ambiguous term 'knowledge'. A "warranted" assertion is an assertion that is supported by strong reasons, provided by the results of continual scientific inquiry, to accept the assertion as true, in the correspondence sense of truth set out by Dewey.

Dewey makes it clear that this correspondence sense of the meaning of the term 'true' is the one that he employs in his theory of knowledge, which he calls "instrumentalism".[22] Dewey writes: "Instrumentalists …do *not* believe the test of truth is coherence; in the operational sense …they hold a correspondence view." (1941, p. 172, fn. 7).

A correspondence conception of truth makes sense when correspondence is understood in the operational sense describe above. The operations of experimental scientific activity make it possible to assess the correspondence truth of a hypothesis by means of experimental evidence, and to build a strong warrant for belief that the dynamics of the occurrent situation are as they are stated to be. The well-warranted assertions that result are knowledge. Scientific inquiry is an ongoing, organized social activity, with a large community of scientists engaged in experimental activity to test the truth of various ideas about the world, and to test and improve the experimental means of testing ideas. The result of scientific inquiry is a set of well-warranted judgments about the correspondence of ideas to the dynamic interactions of the world. Scientific inquiry in this sense is a necessary condition for development of a high-quality body of knowledge, understood as a set of statements strongly warranted to be true of the world.

The term 'knowledge' is ambiguous, as it is used to refer to at least three fundamentally different things. Disambiguation is needed. To refer to well-warranted beliefs about the world developed through scientific inquiry, the term 'modern scientific knowledge' seems *a propos*. To refer to a set of beliefs that has arisen from everyday concourse with the world, though without the benefit of scientific inquiry, it seems that the term 'common-sense beliefs' would serve well. To refer to a set of beliefs not tested by modern scientific inquiry, that are longstanding culturally

[22] The term 'instrumentalism' in Dewey's philosophy refers to the instrumental use of propositions in scientific inquiry, as essential tools of the inquiry process. Dewey's choice of term was unfortunate, as the term 'instrumentalism' has come to denote an epistemological anti-realism, a view that is inconsistent with Dewey's epistemological position, and with modern science.

accepted beliefs about the world, what term should be used? The term 'culturally established belief-system' would seem to be appropriate.

This terminology would be controversial, for the term 'knowledge' has a strong normative connotation. Whatever beliefs are taken to count as knowledge about the dynamic inter-relations in the world are generally understood to be beliefs that are true. Dewey puts it this way: "My analysis of 'warranted assertibility' is offered as a *definition* of the nature of knowledge in the honorific sense according to which only *true* beliefs are knowledge" (Dewey, lw.14.169).

Hence, to use the term 'knowledge' only in connection with scientifically warranted beliefs will be unpopular in some quarters—whatever the source of belief, and to whatever extent the truth of that belief has been tested, it seems that most persons wish their belief-set, however obtained, to be referred to as their "knowledge". But, epistemologically, the distinction between knowledge and belief is fundamental, and should be distinctly marked terminologically. (The term 'scientific knowledge' is thus redundant, but makes up for that by being very clear.)

It may be that the term 'knowledge' has accumulated too many conceptualizations disparate to the meanings implicit in modern scientific knowledge to be useful. It was this consideration that moved Dewey to introduce the term 'warranted assertion' to refer to a modern scientific statement of knowledge, and 'warranted assertibility' to refer to knowledge in the abstract.

4.3.2 Reality and the Objects of Modern Science

Baggott (2013) sets out an informative account of quantum theory in modern physics. Baggott adopts six principles that he asserts are the "Authorized Version" of the fundamental concepts related to modern science. Several of these theses, however, are problematic. Baggott's "Reality Principle" follows a Kantian track: he accepts that "Reality consists of things-in-themselves of which we can never hope to gain knowledge" (Baggott 2013, p.8). We must then, Baggott accepts, "content ourselves with knowledge of empirical reality, of things-as-they-appear or things-as-they-are-measured" (Baggott 2013, p.8). Given the belief that "reality" is inaccessible, Baggott believes that scientific realists can only "assume" that "reality (and its entities) exists objectively and independently of perception or measurement" (Baggott 2013, p. 8). But, having to merely assume this fundamental claim is an unacceptably weak position. The conceptualization of reality given by Baggott needs revision.

Baggott's "Fact Principle" is similarly flawed, leaving modern science inadequately conceived. The statement of this principle begins well: "Our knowledge and understanding of empirical reality are founded on verified scientific facts derived from careful observation and experiment"(Baggott 2013, p. 12). Baggot then adds: "But the facts themselves are not theory-neutral. Observation and experiment are simply not possible without reference to a supporting theory of some kind" (Baggott 2013, p.12).

This principle founders on an ambiguity inherent in the term 'facts'. The term 'the facts' can be used to refer to the actual interactive relations that constitute the world—the dynamic relations of thing/events. The facts, in this sense, will be just what they are, regardless of human beliefs about them, and independent of theories about them. It is only when humans interact with the facts that human beings can bring about changes in a factual situation.

In a different sense, the term 'the facts' can be used to refer to the theoretical interpretations of the interactions of the world, as they are believed to be. In this sense, it is trivially true that "the facts"—the well-tested and well-warranted assertions—are related to the theories one accepts. Because of this ambiguity, it seems advisable to refer to "what is" using the terms 'nature', or 'the world', or the set of 'dynamic interactive events' currently of interest.

Experimental research projects are guided by *tentative* theories, and are designed to test the theory in question. One can truly say that experimental work is, by definition, and *should* be, theory-guided. But, the interactive dynamic relations that constitute reality will occur regardless of the desire of the scientist to see his or her guiding theory confirmed. The results of the testing are independent of the theory being tested, which is to say that the actual interactions undergone are not theory dependent. Expected results are, by definition, theory-dependent, but actual results are not.

4.3.3 Reality, as "What Is", and Truth

An entrée to the ontological question of reality may be made by considering the nature of human beings, and our experience, or, more broadly viewed, the nature of living organisms and our experiences. Living organisms, at a basic level of analysis, are simply certain sorts of happenings, that is, they are things/events which share certain kinds of dynamic interactions with their environment that warrant the classification as "living". Living organisms are simply a subset of the dynamic interactive things/events that, in their entirety, constitute nature, or reality, or "what is". The *experience* of a living organism is not in any way separate, or separable, from the rest of nature, from the dynamic interactions that are natural things/events. The term 'environment' refers to the subset of the surrounding natural thing/events with which the organism is, at a particular time, in interaction with. The environment includes other organisms, as well as every other sort of interactions For example, a human creature is normally in interaction with "breathable air", this being air having the concentration of oxygen and carbon dioxide (along with a vast number of other molecules) that is consistent with the continuing life of the creature. But, the environment can change, and that change can be caused by interactive events that seem far removed from the creature. The organism's environing conditions thus actually extend far beyond the location of the organism.

This view is ontologically naturalistic, in the sense that there is held to be no such thing as a separate other-than-natural sort of Being. On this view, the interactions commonly termed 'mental' are simply a designated subset of natural organismic interactions. The term 'mind' refers to a certain subset of interactions internal to the creature that contribute to determining the activities of the creature. Mind, in this sense, includes cognitive, affective and volitional dynamic interactivities internal to the creature, that tend to guide its action in the environment.

Every organism is in continual interaction with its environing conditions. When the organism is complex enough to respond to certain interactions as signs, taking certain things/events to have significance for action, then the organism has the beginnings of mind. If the significance, *the meaning*, of the interactive experience is retained in the organism, so that past experiences can become operational factors in guiding future actions, then the organism has a full-fledged mind. Mind, in this interpretation, is simply a system of organismically conserved beliefs and dispositions. When intentional social communication of meanings comes into being as an elaborate form of interaction, a language evolves, and a culture begins to develop. When the communicative organisms in a cultural setting are of sufficient social complexity, then, the system of meanings that is mind can be given an extra-organismic place in the world, e.g., in books.

This understanding of organisms, of experience, and of mind, is central to Dewey's naturalistic realism. The "mental" is simply one subset of the dynamic interactions that contribute to determining the actions of the organism.

This view is also ontologically realist, in the sense that the interactions that constitute nature are for the most part not dependent upon the beliefs, wishes or desires of living organisms. The exception is obvious: this "independence of nature from organismic belief" obtains, *except* when the organism itself is one of the causal factors in interaction. As an organism acts, it will, being a natural concatenation of interactive events, participate in the determination of the interactive events that constitute the emerging situation.

But, if an organism fails to (more-or-less) accurately represent the current state of dynamic affairs, the organism will be less able to act in pursuit of its goals, e.g., maintaining its living state. So, for example, in the event of a tornado, the organism's taking shelter will affect the developing situation. But, the organism's *belief that* it is safely sheltered does not mean that it *is* safely sheltered. A belief about the world, by itself, does not affect the dynamic interactions of the world. It is in this particular sense that reality is independent of belief.

Beliefs are only useful to the organism when they do shape the organism's action. The organism's beliefs, and its linguistic statements of belief, if applicable, are only likely to successfully guide action if they are true in the correspondence sense of truth. Modern science is the highly elaborated and rigorously tested process of the testing of tentative, potential beliefs. The goal is to develop knowledge, a set of beliefs about the interactive events of the world, and the conditions and consequences of their occurrence that is well warranted to be true to the world.

4.4 Conclusion

In *Experience and Nature* Dewey wrote, “To entertain and believe fancies which once were spontaneous and general is today a sign of failure, of mental dis-equilibration. Inability to employ the methods of forming and checking beliefs which are available at a given time, whatever be the source of that inability, constitutes a disorientation” (Dewey 1925, lw.1.175).

Respect for persons does not entail respect for the belief-systems of those persons. Respect for persons entails respect for the capacity of those persons to engage in the fundamentally human activities, among which is capacity to search for true belief. Respect for persons thus entails commitment to the support of each person in their quest for true belief. Respect for persons entails, among other things, a commitment to the equal distribution of the social good of education. It means respectful, and mutual, critiques of one another’s belief-systems, leading to mutual thought and the self-critique that is essential to the individual’s growth in cognition and in all other capacities.

To fail to teach to one’s students the critical evaluation of their own current belief-systems, which is necessary in the effort to maximize true belief and to reduce false belief, is a matter of fundamental disrespect for persons, and constitutes a profound mis-education. No culture is free from error, and none is immune to an overgrowth of destructive superstition. Growth in scientific knowledge – a genuine, modern, and growing scientific knowledge – is a necessary condition of effective human action to counter the destructive effects of human action on the global environment, and hence, increasingly, on ourselves.

The state of cultural antagonism, of personal disrespect, and all too often, of hatred for the “other”, the different, is one of humanity’s chief problems. But, the thesis promoted in cultural studies of science education literature, that respect for others requires according equal respect to non-scientific methods of inquiry and to systems of belief about the world not warranted by scientific inquiry, is a recipe for social injustice. The essential goal of science education should be to advance social understanding of the methods of science and scientific knowledge about the dynamics of the world. This is of critical importance if we are to effectively respond to the urgent issues we currently face.

References

Aikenhead, G. (2001). Integrating western and aboriginal sciences: Cross-cultural science teaching. *Research in Science Education, 31*, 337–355.

Aikenhead, G. (2014). *Enhancing school science with indigenous knowledge: What we know from teachers and research*. Saskatoon: Saskatoon Public School Division.

Aikenhead, G., & Ogawa, M. (2007). Indigenous knowledge and science revisited. *Cultural Studies of Science Education, 2*, 539–620.

Baggott, J. (2013). *Farewell to reality: How modern physics has betrayed the search for scientific truth*. New York: Pegasus Books.
Berkes, F. (1999). *Sacred ecology: Traditional ecological knowledge and resource management*. Philadelphia: Taylor & Francis Publishers.
Boyer, P. (Ed.). (2010). *Ancient wisdom, modern science: The integration of Native knowledge in math and science at tribally controlled colleges and universities*. Pablo: Salish Koottenai College Press.
Bradley, R. S. (2011). *Global warming and political intimidation: How politicians cracked down on scientists as the earth heated up*. Amherst: University of Massachusetts Press.
Brickhouse, N. W. (2001). Embodying science: A feminist perspective on learning. *Journal of Research in Science Teaching, 38*(3), 282–295.
Bunge, M. (1967/1998). *Philosophy of science: From problem to theory*. New Brunswick: Transaction Publishers.
Bunge, M. (2006). *Chasing reality: Strife over realism*. Toronto: University of Toronto Press.
Cajete, G. (2000). *Native science: Natural laws of interdependence*. Santa Fe: Clear Light Publishers.
Cook, J., Oreskes, N., Doran, P., Anderegg, W., Verheggen, B., Maibach, E. Carlton, J. Lewandowsky, S., Skuce, A., Green, S., Nuccitelli, D., Jacobs, P., Richardson, M., Winkler, B., Painting, R., & Rice, K. (2016, April 13). *Consensus on consensus: A synthesis of consensus estimates on human-caused global warming*. http://iopscience.iop.org/article/10.1088/1748-9326/11/4/048002/pdf
Cordero, A. (2001). Scientific culture and public education. In F. Bevilacqua, E. Giannetto, & M. R. Matthews (Eds.), *Science education and culture: The contribution of history and philosophy of science*. Dordrecht: Kluwer Academic Publishers.
Deloria, V. (1997). *Red earth, white lies: Native Americans and the myth of scientific fact*. Golden: Fulcrum Publishing.
Deloria, V. (2002). *Evolution, creationism, and other modern myths: A critical inquiry*. Golden: Fulcrum Publishing.
Devitt, M. (1991). *Realism and truth* (2nd ed.). Oxford: Blackwell Press.
Devitt, M. (2012). Scientific realism. In P. Greenough & M. P. Lynch (Eds.), *Truth and realism*. Oxford: Oxford University Press.
Dewey, J. (1907). The control of ideas by facts. In J. Boydston, (Ed.), *Collected works of John Dewey* (Middle works 4, pp. 78–90). Carbondale: Southern Illinois University Press.
Dewey, J. (1925). Experience and nature. In J. Boydston, (Ed.), *Collected works of John Dewey:* (Later works 1, pp. 3–437). Carbondale: Southern Illinois University Press.
Dewey, J. (1941). Propositions, warranted assertibility, and truth. In J.A. Boydston, (Ed.), *Collected works of John Dewey*: (Later works 14. pp. 168–188. Carbondale: Southern Illinois University Press.
Dunlap, R., & McCright, A. (2014). A widening gap: Republican and democratic views on climate change. *Environment: Science and Policy for Sustainable Development, 50*(September/October 2008), 26–35.
Elkana, Y. (1971). The problem of knowledge. *Studium Generale, 24*, 1426–1439.
Elmesky, R. (2011). Rap as a roadway: Creating creolized forms of science in an era of cultural globalization. *Cultural Studies of Science Education, 6*, 49–76.
Farrell, F. B. (1996). *Subjectivity, realism, and postmodernism: The recovery of the world*. Cambridge: Cambridge University Press.
Gellner, E. (1974). *The legitimation of belief*. London: Cambridge University Press.
Griffin, D. (Ed.). (1988a). *The reenchantment of science: Postmodern proposals*. Albany: State University of New York Press.
Griffin, D. (1988b). Introduction: The reenchantment of science. In D. Griffin (Ed.), *The reenchantment of science: Postmodern proposals*. Albany: State University of New York Press.
Harding, S. (1996). Gendered ways of knowing and the "epistemological crisis" of the West. In N. Goldberger, J. Tarule, B. Clinchy, & M. Belenky (Eds.), *Knowledge, difference and power: Essays inspired by women's ways of knowing* (pp. 431–454). New York: Basic Books.

Harman, W. (1988). The postmodern heresy: Consciousness as causal. In D. Griffin (Ed.), *The reenchantment of science: Postmodern proposals* (pp. 115–128). Albany: State University of New York Press.

Irwin, A., & Bednarz, N. (1998). Constructivism and education: Beyond epistemological correctness. In M. Larochelle, N. Bednarz, & J. Garrison (Eds.), *Constructivism and education* (pp. 3–20). Cambridge: Cambridge University Press.

Landau, I. (2008). Problems with feminist standpoint theory in science education. *Science & Education, 17*, 1081–1088.

Langdon, J. (Ed.). (2009). *Indigenous knowledges, development and education*. Rotterdam: Sense Publishers.

Larochelle, M., Bednarz, N., & Garrison, J. (Eds.). (2009). *Constructivism and education*. Cambridge: Cambridge University Press.

Mahner, M., & Bunge, M. (1996). Is religious education compatible with science education? *Science & Education, 5*(2), 101–123.

Matthews, M. R. (2004). Reappraising positivism and education: The arguments of Philipp Frank and Herbert Feigl. *Science & Education, 13*(1–2), 7–39.

Matthews, M.R. (2015). Science teaching: The contribution of history and philosophy of science, 2nd Updated Edn, New York: Routledge.

McCarthy, C. (1996a). When you know it and I know it, what is it we know? Pragmatic realism and the epistemologically absolute. *The Proceedings of the Philosophy of Education Society, 1996*, 21–29.

McCarthy, C. (1996b). Does "the knowing" alter "the known"? On the troubling relation of facts and ideas in a Deweyan epistemology. *Education and Culture: The Journal of the John Dewey Society, 13*(2), 18–28.

McCarthy, C. (2000, Spring). Deweyan pragmatism and the quest for true belief. *Educational Theory, 2000*, pp. 217–227.

McCarthy, C. (2002). Claiming to know: Objectivity, truth and science. *Philosophy of Education Yearbook, 2001*, 346–348.

McCarthy, C. (2007a). Meaning, mind and knowledge: A pragmatic view. *Philosophy of Education Yearbook, 2007*, 421–429.

McCarthy, C. (2007b). The quest for transcendence in Dewey's pragmatism, or, the view not held. *Studies in Philosophy and Education, 26*, 345–362.

McCarthy, C. (2014). Cultural studies in science education: Philosophical considerations. In M. R. Matthews (Ed.), *International handbook of research in history, philosophy and science teaching* (pp. 1927–1964). Dordrecht: Springer.

McCarthy, C. (2017). Chapter 17: Science in the course of study. In L. Waks (Ed.), *Centennial handbook on Dewey's democracy and education*. Cambridge: Cambridge University Press.

McCarthy, C., & Sears, E. (2000). Science education: Constructing a true view of the real world? *Philosophy of Education Yearbook, 2000*, 369–377.

Medin, D., & Bang, M. (2014). *Who's asking? Native science, western science and science education*. Cambridge, MA: The MIT Press.

Merchant, B. (2015). *The most anti-science congress is recent history is now in session*. http://motherboard.vice.com/read/meet-the-most-anti-science-congress-in-modern-history

Metallic, J. (2009). Exploring Indigenous ways of knowing, being and doing in developing a cross-cultural science curriculum. In J. Langdon (Ed.), *Indigenous knowledges, development and education* (pp. 97–108). Rotterdam: Sense Publishers.

Meyer, X., & Crawford, B. (2011). Teaching science as a cultural way of knowing: Merging authentic inquiry, nature of science, and multicultural strategies. *Cultural Studies of Science Education, 6*, 525–547.

Nagel, T. (2012). *Mind & cosmos: Why the materialist neo-Darwinian conception of nature is almost certainly false*. Oxford: Oxford University Press.

Nicodemus, Y. (2013). *Theory of African metaphysics*. Copyright: Yongho N. Nichodemus.

Ogawa, M. (1995). Science education in a multiscience perspective. *Science Education, 79*(5), 583–593.

Ogawa, M. (1998). Under the noble flag of 'developing scientific and technological literacy'. *Studies in Science Education, 31*(1), 102–111.

Omoregbe, J. (1990). *Knowing philosophy: A general introduction*. Lagos: Joja Educational Research and Publishers, Ltd..

Pavlik, S. (2014). *The Navaho and the animal people: Native American traditional ecological knowledge and ethnozoology*. Golden: Fulcrum Publishing.

Peat, F. D. (2005). *Blackfoot physics: A journey into the native American universe*. Boston: Weiser Books.

Peirce, C. (1986/1878). The fixation of belief. In *Writings of Charles S. Peirce: A chronological edition, Vol. 3: 1872–1878* (pp. 242–256). Bloomington: Indiana University Press.

Pigliucci, M. (2010). *Nonsense on stilts: How to tell bunk from science*. Chicago: The University of Chicago Press.

Popper, K. (2002/1935). The logic of scientific discovery. New York: Routledge (first published 1935, as *Logic der Forschung,* Verlag von Julius Springer, Vienna, Austria)

Rescher, N. (1984/1999). *The limits of science* (Rev. Edn). Pittsburgh: University of Pittsburgh Press.

Ritskes, E. (2011). Indigenous spirituality and decolonization: Methodology for the classroom. In G. Sefa Dei (Ed.), *Indigenous philosophies and critical education: A reader* (pp. 367–385). New York: Peter Lang.

Roth, W. (Ed.). (2009). *Science education from people for people: Taking a stand(point)*. New York: Taylor & Francis Books.

Roth, W., & Barton, A. C. (2004). *Rethinking scientific literacy*. New York: Taylor and Francis Books.

Roth, W., Tobin, K., & Ritchie, S. (2001). *Re/constructing elementary science*. New York: Peter Lang.

Sefa Dei, G. (Ed.). (2011). *Indigenous philosophies and critical education: A reader* (pp. 367–385). New York: Peter Lang.

Shahjahan, R., & Haverkos, K. (2011). Revealing the secular fence of knowledge: Towards reimagining spiritual ways of knowing and being in the academy. In G. Sefa Dei (Ed.), *Indigenous philosophies and critical education: A reader* (pp. 367–385). New York: Peter Lang.

Siegel, H. (1997). Science education: Multicultural and universal. *Interchange, 28*(2–3), 97–108.

Smith, W. (2013). *Ancient wisdom and modern misconceptions: A critique of contemporary scientism*. Kettering: Angelico Press.

Snively, G., & Corsiglia, J. (2001). Discovering indigenous science: Implications for science education. *Science Education, 85*, 6–34.

Sorell, T. (1994). *Scientism: Philosophy and the infatuation with science*. New York: Routledge.

Staver, J. (1998). Constructivism: Sound theory for explicating the practice of science and science teaching. *Journal of Research in Science Teaching, 35*(5), 501–520.

Stocker, T. F., Qin, D., Plattner, G. K., Tignor, M., Allen, S. K., Boschung, J., Nauels, A., Xia, Y., Bex, V., & Midgley, P. M. (Eds.). (2014). *Climate change 2013: The physical science basis. contribution of working group I to the fifth assessment report of the intergovernmental panel on climate change*. Cambridge: Cambridge University Press.

Tobin, K. (2015). Connecting science education to a world in crisis. *Asia-Pacific Science Education, 1*, 1–21.

Tobin, K., & Tippins, D. (1993). Constructivism as a referent for teaching and learning. In K. Tobin (Ed.), *The practice of constructivism in science education*. Washington, DC: American Association for the Advancement of Science Press.

Vision, G. (2004). *Veritas: The correspondence theory and its critics*. Cambridge: The MIT Press.

von Glaserfeld, E. (1993). Questions and answers about radical constructivism. In K. Tobin (Ed.), *The practice of constructivism in science education*. Washington, DC: American Association for the Advancement of Science Press.

Williams, R. (2015). Introduction. In R. Williams & D. Robinson (Eds.), *Scientism: The new orthodoxy*. London: Bloomsbury Academic.

Wolpert, L. (1992). *The unnatural nature of science: Why science does not make (common) sense*. Cambridge, MA: Harvard University Press.

http://thinkprogress.org/climate/2013/12/11/3045841/house-science-hearing-weather-climate/

http://thinkprogress.org/climate-denier-caucus-114th-congress/

http://www.joanneoellers.com/wp-content/uploads/2014/03/Republican-and-Democratic-Views-on-Climate.pdf

http://www.theguardian.com/environment/2015/jun/11/james-inhofe-republican-climate-denier-pope-francis

https://www.texastribune.org/2015/03/24/ted-cruz-texas-tribune-interview/

https://www.washingtonpost.com/blogs/post-partisan/wp/2016/03/21/a-transcripteditorial board -of-donald-trumps-meeting-with-the-washington-post-editorial-board/

Part II
Teaching and Learning Science

Chapter 5
Epistemic Practices and Science Education

Gregory J. Kelly and Peter Licona

This chapter draws from the empirical studies of scientific practice to derive implications for science teaching and learning. There has been considerable empirical work from multiple disciplines (cognitive science, sociology, anthropology, rhetoric) informing perspectives about science and the inner workings of scientific communities and institutions. These interdisciplinary science studies examine the practices, discourses, and cultures of scientists and scientific communities. While the empirical study of science has a considerable history, including informing a naturalized philosophy of science, it is an area often less emphasized for informing education. Such empirical studies of science offer insights about science, provide implications for science learning, and model ways of investigating knowledge in action. These studies of disciplinary practices have parallels in education where ethnographic studies of the everyday work of teaching, learning, and schooling have a long tradition. Such studies examine the cultural practices of educational phenomena in various settings, and similarly provide insights into the ways that knowledge is proposed, communicated, evaluated, and legitimized through sociocognitive practices.

The authors would like to thank Richard Duschl and the members of the Penn State Education Discourse Group (Matthew Johnson, Yann Shiou Ong, Arzu Tanis Ozcelik, Jisun Park, Amy Ricketts, Lucia Sasseron, Carmen Vanderhoof) for comments on an earlier draft of this chapter.

G.J. Kelly (✉)
College of Education, The Pennsylvania State University, State College, PA, USA
e-mail: gkelly@psu.edu

P. Licona
Elizabethtown College, PA, USA
e-mail: liconap@etown.edu

M.R. Matthews (ed.), *History, Philosophy and Science Teaching*, Science: Philosophy, History and Education, DOI 10.1007/978-3-319-62616-1_5

A key contribution of this empirical work on the practice of knowledge construction is the shift in the consideration of the epistemic subject from the individual knower to that of a relevant social group. This research adds to the work in philosophy identifying limitations of epistemologies based in, or assuming, a Cartesian subject. This shift suggests the need to examine the social processes determining what counts as knowledge, to consider a communal understanding of meaning, to evaluate ideas set in historical and public contexts, and to recognize the importance of the assessment of knowledge claims by relevant groups. Such social processes can become routinized and patterned over time becoming epistemic practices. These epistemic practices include public reasoning and adjudication of competing claims for knowledge.

Epistemic practices are the socially organized and interactionally accomplished ways that members of a group propose, communicate, evaluate, and legitimize knowledge claims. Drawing from studies of science and education, this chapter argues that epistemic practices are interactional (constructed among people through concerted activity), contextual (situated in social practices and cultural norms), intertextual (communicated through a history of coherent discourses, signs and symbols), and consequential (legitimized knowledge instantiates power and culture). Through application of these epistemic practices, communities justify knowledge claims.

Through a review of research from education and science studies, the argument for the relevance of a focus on epistemic practices is developed. From this point of view, a number of implications for developing conceptual understanding, for learning, and for research methodology in science education are derived. The chapter shows how the use of empirical studies of scientific knowledge and knowledge construction processes in schools offers contributions to thinking about science education. This perspective complements the important normative work in epistemology to provide a balanced view of history, philosophy, and sociology of science in science education.

5.1 Education Goals for Science and Engineering Education

In a review of major reforms in science education over the past 50 years, Duschl (2008) drew from learning science and science studies to propose that science education be organized around conceptual, epistemic, and social learning goals. While these goals can be delineated, they do not appear as separate objectives of a given science lesson. Rather, they are to be integrated into lessons and experiences with each building off and supporting the others. For example, Duschl notes the importance of building models, constructing arguments, and using specialized forms of language in scientific communities. Such social practices involve and are dependent on cognitive processes and a history of conceptual knowledge that is brought to bear on decisions about argument and models (Toulmin 1972). Recognizing these goals are integrated and central to effective science education makes a shift away from only the products of science, to a view of science that includes the evidentiary bases for knowledge and need for participation in the cultural practices leading to knowledge construction (Kelly 2008, 2016; Longino 2002). The construction and assessment of models, reasoning, and communication each entail use of specialized discourse (Kelly 2014a), and lead to ways that educational goals for science instruction tie to scientific literacy.

Debates about scientific literacy have a history with many educational goals and purposes (DeBoer 2000). Conceptual, epistemic, and social goals all entail the uses of discourses (spoken, written, symbolic) and pose communicative demands on students. Building on these goals for science education is a set of considerations around the uses of language for learning. Norris and Phillips (2003) identified two broad forms of scientific literacy, fundamental and derived. Derived scientific literacy refers to the knowledge to be an informed citizen about science and socioscientific issues. These authors argue that to develop effective knowledge about socioscientific issues (derived sense of literacy), students need to be proficient in reading and writing scientific texts (fundamental sense). The argument we develop builds on this importance of language, but further considers how discourse processes are central to the work of constructing, communicating, evaluating, and legitimizing knowledge claims (Kelly 2011). Discourse refers to language-in-use, including verbal and non-verbal communication and uses of inscriptions, signs, and symbols. Discourse positions people in social groups and identities. Social norms, expectations, and practices are constructed through such discourse processes over time, and in turn shape uses of discourse; thus, discourse both shapes and is shaped by sociocultural practices. Discourse practices are central to the processes of seeking, building, and refining knowledge claims in science.

Across views of scientific literacy there is a common commitment to the need to develop understandings of science in context and to bring ethical and moral considerations to bear on socioscientific decision-making. For example, Aikenhead et al. (2011), aim to develop capacity to engage with issues from a scientific perspective. They suggest that this capacity focus on knowing how to learn and developing knowing-in-action. From this perspective, propositional knowledge of science is too limited a goal. They propose rather that curricular goals for science build on a triad of content, processes, and contexts. Through a review of perspectives on scientific literacy, Norris, Phillips, and Burns (2014) characterize intended outcomes of scientific literacy into three categories: values regarding states of knowing, values regarding capacity to engage with science in context, and values regarding moral and intellectual development of learners.

These arguments for scientific literacy build a view of learning that entails a "mastery of a range of epistemic practices" (Saljo 2012, p. 10) that require knowing how to draw from the texts, signs and symbols of relevant communities and employ concepts in the processes of knowledge construction. Learning the discourse processes of epistemic cultures occurs through acculturation into the ways of being instantiated by members of local communities (Kelly and Green 1998). Such local communities develop social language with unique features. For science, there are commonalities across social languages, for example the formalization of certified

Table 5.1 Variation in foregrounding of the articulation of three educational goals across three approaches to teaching science

Disciplinary approach:	Science	Engineering	Socioscientific issues
Educational goals:			
Conceptual	Construction and understanding of plausible models for representing and making sense of natural world	Design, analysis, and construction of models and technologies for specified purposes	Construction and understanding of science concepts and moral, personal, religious perspectives
Epistemic	Understanding of the reasons, evidentiary bases for conceptual knowledge and models	Understanding and optimizing the functioning of technologies and evidentiary bases for measures of success	Understanding the multiple perspectives (e.g., scientific, moral, personal, religious) for the construction of coherent line(s) of reasoning supporting a position(s) on a controversial issue
Social	Recognize the procedures used by epistemic cultures to generate, communicate, and evaluate knowledge claims	Recognize the procedures used by design and analysis teams and role of client in generating, communicating, and evaluating technological designs	Recognize the procedures for generating, communicating, and evaluating arguments supporting particular position(s) on an issue

propositional knowledge, and variations, such as ways such knowledge is talked into being in local contexts (e.g., field-based ecology research group, after school science club). Learning science requires participation in a community of more knowing others that provides contexts for use of social languages where acquisition of scientific social languages is possible (Leach and Scott 2003).

Such participation holds regardless of the diversity of emphases in science learning—products or processes of science. Different science curricula will place emphasis on different aspects of the conceptual, social, and epistemic goals for education. To illustrate some of these differences we consider three types of curricula, science as inquiry (Kelly 2014b), engineering education (Cunningham and Carlsen 2014), and socioscientific issues (Sadler 2004; Zeidler 2014). These orientations toward knowledge and products of knowledge across the three types of educational goals (conceptual, epistemic, social) are presented in Table 5.1. This table demonstrates the ways educational goals vary across three approaches to teaching science. In each disciplinary approach, different conceptual, epistemic, and social practices are foregrounded.

Developing knowledge, values, and capacity to apply knowledge in action requires a recognition by educators of a commitment to “certain paths and goals of development and growth” that are more valuable than others (Norris et al. 2014, p. 1319). The argument we develop here is that this commitment is not just to learning the products of science, but rather involves understanding the importance and value of the disciplinary nature of science and engineering fields. This means that our view of epistemology is not one of a personal way of knowing, but rather that there are disciplinary ways of knowing that can be empowering for learners and recognized by legitimizing institutions. Thus, we turn to studies of science in action (history, philosophy and sociology of science, plus anthropology and rhetoric of science), to examine the processes and values associated across four categories of epistemic practices - proposing, communicating, evaluating, and legitimating knowledge claims.

5.2 History, Philosophy, and Sociology of Science (HPS) and Epistemic Practices

Studies in the History, Philosophy, and Sociology (HPS) of science and science teaching have drawn largely from the fields of history and philosophy. For example, a recent comprehensive HPS handbook (Matthews 2014) leaves sociology out of the title and largely out of the series of chapters. The perspectives in this handbook and elsewhere drawing from history and philosophy of science are valuable and have advanced thinking in education in a number of ways (e.g., Duschl 1990; Matthews 2015), including setting a prominent role for disciplinary knowledge in considerations of educational aims. To complement such perspectives, in this chapter we draw from an alternative body of literature that sets scientific knowledge and practice (i.e., science-in-the-making, Kelly et al. 1998) as the foci of empirical investigation. Studies from anthropology, sociology, and rhetoric of science have been introduced into conversations about science education in a number of ways over an extended period of time.[1]

Studies from the sociology of science have been ignored and often criticized in science education (e.g., Koertge 1998; Slezak 1994a, b; for alternatives, see Allchin 2004; Kelly 2005). Such criticisms often focus on the ways that sociology of science can be interpreted to offer a debunking critique of science. The emphasis on the social, causal explanations for the success for scientific theories and scientists by sociologists (Collins 1985) appears to run counter to not only the value of epistemology as a discipline, but also to a central educational goal of developing rationality among students. In a more recent book, Collins (2014) noted how a sociological understanding of science has identified the unique values, commitments, and expertise of scientific communities (p. 124), which cohere with educational goals. While we recognize problems in the sociology of science, we make three counter arguments to such criticisms, and in doing so leave open the possible value of the empirical study of scientific practices.

First, it is important to differentiate normative from descriptive accounts of social practice. Translating descriptions of actual practice to normative goals misses the central point of the empirical studies of practice. Normative goals may be informed

[1] See: Collins 2007; Ford 2008; Heckler 2014; Kelly and Bazerman 2003; Kelly et al. 1993; Kelly and Crawford 1997; Roth et al. 1996; Stewart and Rudolph 2001.

by studies of everyday life in social settings, but such educational goals are dependent on deontological arguments that include a range of considerations beyond a replication of current practice. Empirical studies of practice identify how knowledge is constructed *in situ*; this may expand the range of understanding about knowledge construction, but not every behavior needs to contribute to normative goals. Second, for the purposes of educational theory, sociology of science and other empirical studies of science need to be read and understood from an educational point of view. Such studies may expand the range of knowledge about science, bring to light inner workings of epistemic cultures, and identify ways that claims are modified through experimental and textual work. These valuable insights can contribute to the development of educational programs without suffering from excesses of a relativist epistemology (Allchin 2011). Third, ethnographic studies of science from sociology and anthropology offer a range of methodological orientations and approaches to understanding cultural practices of science. The overall stance of investigating science-in-the-making through inquiry into how knowledge is produced offers a model for studies of education (Kelly et al. 1998). This approach asks similar questions about what counts as knowledge in school settings. The examination of the ways that groups produce knowledge offers a model that can be taken up in education.

5.2.1 Illustrative Examples of Epistemic Practices from Education Informed by Science Studies

We define epistemic practices as the socially organized and interactionally accomplished ways that members of a group propose, communicate, evaluate, and legitimize knowledge claims (Kelly 2008, 2016). Social practices are patterned actions that are recognizable among members of a group. Epistemic practices are central to both science and education. Practices are learned through participation and often entail extended interactions with members already familiar with the ways that practices are recognized as socially significant. Such practices are not static over time and may be contextualized to relatively local groups – for example, a laboratory technique may be invented and used in a local context of research before being spread with various dissemination activities. Thus, epistemic practices are defined and acknowledged in a group that can be very localized and mutable, or extend to large membership through formulation (e.g., Hamiltonian function, standardized laboratory protocols). These epistemic practices are formed in endogenous communities and may be constructed and extended, modified and changed, and are based in substantive assumptions, such as the ontological categories of a discipline. Furthermore, in education, there are various forms of epistemic practice that vary with relevant pedagogical goals. For example, epistemic goals of an inquiry lab may be significantly different than those of a debate regarding socioscientific issues.

Since epistemic practices are field- and time-dependent (changing due to the challenges of knowledge production), there is not a limited set of “science practices.” This contrasts with how “the scientific method” is often interpreted in education as a set of linear steps. Rather, there are disciplinary (and other!) ways of knowing that vary across the multiple ways that humans make sense of their experience. The point is not to define a given set of eight practices (NGSS Lead States 2013), or the five steps of the scientific method. Rather, the idea is to identify the ways people come to know and recognize the value of making sense in systematic ways that render evidence open for public scrutiny and evaluation.

To illustrate the four categories of epistemic practices (ways of proposing, communicating, evaluating, and legitimizing knowledge), we draw from a series of education studies of Kelly and his colleagues. These studies represent an empirical program of epistemology – that is, they focused on what counts as knowledge, reasoning, justification, and representation in science education settings. The studies were informed by science studies and educational ethnography.

One dimension of epistemic practices concerns the value of *proposing knowledge claims*. Kelly et al. (2001) examined the discourse processes of four physics groups studying oscillatory motion. The student discourse was analyzed from a sociolinguistic perspective that considered the verbal and non-verbal communication, which included the signs and symbols, proxemics, and prosody of the conversations (Green et al. 1988; Gumperz 2001). The student groups made a series of knowledge claims. In this example, students needed to make interpretation of the physical events (oscillating masses), symbols (real-time, computer generated graphs), verbal and written prompts (student talk, teacher lab guide sheet), and embodied motion (student imitation of motion through physical movement of hands). The basis for much of the generation of knowledge claims was produced by the data acquisition and representation technologies. The computer generated visual texts were a consequence of the live complex physical phenomena and offered sufficient interpretative flexibility (Knorr-Cetina 1995) to provoke sustained conversation. Thus, a series of knowledge claims, often as false starts and initial thinking, were central to the activity by providing a focus for the students' processes of deliberation about the phenomena. The knowledge gleaned from the educational experience was supported by these knowledge claims – that is, ways of proposing assertions about the physical phenomena.

The methodological orientation was supported by studies of scientific practice, including Garfinkel et al. (1981) analysis of the "local, interactionally produced, recognized, and understood embodied practices" (p. 135) of astronomers through the processes of discovering, naming, and textually identifying a pulsar. Much like the astronomers, the physics students made sense of the phenomena by proposing a series of claims that were considered and modified over time by the group members.

Kelly and Brown (2003) examined the communicative demands of learning science through technological design. In this case, third grade students were tasked with using science to inform the design of functioning solar energy devices. *Communicating knowledge claims* is central to the development of knowledge generation. In this instance, the knowledge claims emerged from a series of events that required the students to work together in teams to study designs, brainstorm ideas, negotiate and renegotiate design strategies, and test and evaluate their solar devices. The students participated in multiple speech situations, where knowledge of science, materials, and phenomena were in question. Knowledge claims were forwarded to multiple audiences (e.g., small student groups, presenting ideas to classmates, student "scientific" reporter). The technological design challenge offered students multiple forums for drawing from extant knowledge and for advancing their own thinking. In this study, the students were situated in forums where discourse was central to the academic and scientific task. They needed to use sense making, persuasion, and representation of their thinking. While the substance of the communication differed from the formalization often found in scientific texts, the epistemic practices and the need for formulating evidence in particular ways is analogous to the discursive work of scientists (Bazerman 1988; Traweek 1988). The inquiry processes and engineering designs necessitating communication and, in particular, forwarding knowledge claims deemed persuasive by the relevant audience.

Takao and Kelly (2003) applied rhetoric of science and argumentation analysis to consider ways of recognizing and evaluating adherence to scientific genres in writing. *Assessing the merits of the presentation of evidence* is one way that knowledge claims can be evaluated. Drawing from rhetoric of science (Bazerman 1988; Gross 1989) and theories of argumentation (Kuhn 1992), this study first reviews key features of evidentiary-based arguments in science. Scientific evidence is presented in particular genres (patterned uses of language) with unique features—that is, knowledge claims are justified through socially accepted ways of presenting evidence. The study focused on methods of assessment of university students' uses of evidence regarding plate tectonics. Through a review of the literature and the analysis of the students' written arguments, key features of the situated nature of the genre of writing evidence were examined. In this case, the formulation of evidence entailed building from low inference claims to progressively higher order theoretical claims, while identifying coherence across epistemic levels of generality. The analysis of the students' papers identified this genre-specific feature of using evidence in geology. These features were difficult for even experienced graduate student instructors to recognize in others' writing. The example shows while the assessment of knowledge claims is important in science, the processes often remain tacit and unrecognizable for participants. This is an example of how science studies can make visible the epistemic practices associated with assessment knowledge claims.

In a study by Reveles et al. (2004), the teacher (Cordova) positioned his students to *legitimize a scientific point of view* amidst competing ways of thinking about natural phenomena. In this third grade classroom the students are introduced to a set of epistemic practices (organized around investigating, communicating, and using evidence). In this case, the goal of developing improved scientific literacy required more than learning the conceptual knowledge of science, or even the abilities to read and write science (Norris and Phillips 2003) – although the uses of language was an important component. In this example the teacher made reference to science and scientists in an effort to develop students' knowledge of disciplinary practices. He was able to accomplish this through meta-discourse, talk about the classroom talk. In doing so, he built on students' initial ideas and made reference to how they were using scientific concepts to understand phenomena. This is an example of how fostering epistemic practices among young students differs from the uses of such practices in science fields.

In the educational context, a key piece of the learning experience entailed developing students' identities as science learners capable of participating and making sense of scientific practices. This is just one way that knowledge can be legitimized in and through classroom discourse. There are multiple ways that knowledge can be legitimized in science and engineering fields (Pinch 1986). These legitimation processes often entail uses of texts and peer review and many agonistic struggles and competition (Latour 1987; Myers 1989, 1997). Knowledge claims can be proposed, communicated, and assessed, without entering into the socially recognized public knowledge and thus through the processes of legitimation such knowledge claims can become scientific knowledge.

5.2.2 Emerging Themes from Study of Epistemic Practices in Science and Education

5.2.2.1 Contexts of Knowledge Claims

Across the four studies mentioned in the previous section, and others in education building on science studies (Jiménez-Aleixandre 2014), an important feature of the learning process is a focus on knowledge across three types of contexts. In philosophy of science, there was a distinction made between the (often messy and confusing) context of discovery and the (inferentially tight) context of justification. Both of these are important for science learners. The context of discovery provides opportunities to learn about instrumentation, how ideas connect to phenomena, and how knowledge claims change through inquiry. The context of discovery also provides opportunities to learn about how seemingly subject-dependent processes such as observation, require cultural knowledge to learn how to observe (Norman 1998). The context of justification remains important, not only to understand how theories change over time (e.g., Duschl 1990; Matthews 2015), but also to understand the ways that evidence gets marshaled in science (Duschl and Grandy 2008). Another context of equal importance is the context of communication and presentation. This context does not occur after the inquiry processes, when the knowledge claims are completed, but throughout the contexts of discovery and justification, as knowledge claims are conceived, put forth, debated, formulated, reviewed, critiqued, and revised. For this, context issues of persuasion and audience play a central role.

5.2.2.2 Epistemic Subject as Local Endogenous Community

Studies of epistemology in science education have been based on the epistemology of scientific knowledge (e.g., views of theory change and rationality), or personal epistemologies of individual learners (e.g., how views of knowing influence learning). An alternative view informing this chapter emerges from studies of epistemology *in situ*, focusing on the situated contextual practices of knowledge construction (Kelly et al. 2012). From this point of view, the locus of attention centers on how participants in an epistemic culture decide what counts as evidence, knowledge, and justification. The practices view of epistemology can be informed by both the study of disciplinary knowledge or of learners' views of knowing, but also reorganizes the research approaches to actual practices of knowledge construction. From this point of view, a key feature of knowing is the recognition of the local endogenous community as the relevant epistemic subject (Kelly 2008; Longino 1993).

Situating the epistemic subject in a relevant community of knowers suggests a view of learning as socialization into ways of being, knowing, interacting, and participating. Learning occurs through participation and engagement. Central to such participating is developing social meanings for terms, concepts, processes, and ways of being in a field. Under this orientation, teachers aim to engage students in epistemic practices through knowledge constructing activities. From theories of language socialization, it is clear that it takes significant socialization and acculturation to have meaningful conversations about substantive scientific concepts and procedures (e.g., s and p orbitals in atoms, mass spectroscopy).

As proposers of knowledge claims seek greater generality, claims migrate through increasingly broader levels of critique and legitimation. Longino (1990, 2002) proposed a set of social norms for the development of social (scientific) knowledge. Longino recognized the important role of social processes and values in the evaluation and legitimation of knowledge claims. The four norms are the following: The *venue* refers to the need for publicly recognized forums for the criticism of evidence, methods, assumptions, and reasoning (e.g., research meetings, conference presentations, and publications). *Uptake* refers to the extent to which a community tolerates dissent, and subjects its beliefs and theories to modification over time in response to critical discourse. A basis for criticism of the prevailing theories occurs through *publicly recognized standards*. These standards frame debates and criticism and evolve over time as research groups, communities and disciplines develop new knowledge and practices. Finally, Longino (2002) argued for communities characterized by *equality of intellectual authority*, tempered by relevant levels of expertise and knowledge.

Longino's argument is that such social norms are prescriptive – offering a normative account for public discourse in science. Such norms may be adaptable for learning contexts in education (Kelly 2014b). Longino's perspective offers ways of integrating the results from the practices of inquiry into the social knowledge recognized and legitimized by an epistemic culture, thus showing the importance of normative considerations for epistemology.

5.3 Epistemic Practices in Science and Engineering Education

Studies of scientific and engineering practices offer a number of implications for science and engineering education. These studies contribute to the important dimension of curriculum validity by considering the epistemological dimensions of education. By identifying what counts as science, design, engineering, experiment, and so forth, these studies open a range of possibilities for inventive, creative curriculum development. The study of professional practice and the epistemic cultures producing knowledge provides insights into not only how science and engineering are conducted, but also the ways in which knowledge is proposed, communicated, evaluated, and legitimized. Furthermore, ethnographic, sociological, and rhetorical studies of the actions, practices, and texts of professional practice offer models for the study of knowledge in education settings. These implications are noteworthy and complement the work that has emerged from the history and philosophy of science. Nevertheless, studies of professional practices cannot be taken without careful consideration of the educational contexts (McDonald and Songer 2008). Students often have considerably less knowledge and fewer and less developed habits of mind to bring to bear on issues of inquiry. Although when working under conditions with proper scaffolding, students have been shown to engage in knowledge building and reasoning (Lehrer and Schauble 2012), ethnographies of science also identify the highly competitive and sometimes ruthless rivalries in professional communities that would be detrimental to educational purposes. So, while HPS, and in particular the empirical study of science and engineering practice, has demonstrable value for science education, such studies must be read from an educational point of view where issues of ethics, pedagogy, and human development outweigh views of authenticity. There are a number of emerging research programs in education that build on science studies, taking carefully considered readings of this work into the study of epistemic practices in education.

5.3.1 Research Programs Regarding Epistemic Practices in Science Education

Science studies have been taken up and applied to science education in a number of contexts and across a range of educational purposes (e.g., Kelly et al. 1993; Kelly and Crawford 1997; Roth et al. 1996). We now turn to research in science and engineering education that brings science studies perspectives to education. These studies have a common orientation to consider epistemological issues as interactionally accomplished among members of an educational community for specific goals (Kelly et al. 2012). In this section we answer the question: What does a focus on epistemic practice contribute to the field of history, philosophy, and sociology of science and science teaching (HPS&ST)?

5.3.1.1 Nuanced Understandings of Language and Its Relationships to Meaning

As we view epistemic practices as the socially organized and interactionally accomplished ways that members of a group propose, communicate, evaluate, and legitimize knowledge claims, engaging in epistemic practices involves making meaning among people through discourse. Discourse is language-in-use and includes spoken and written language, uses of signs and symbols, and non-lexical elements of communication such as body language and eye gaze. A number of studies in science education address epistemological questions through the study of discourse processes. One such research program follows an approach labeled the practical epistemology analysis (Lidar et al. 2010; Ostman and Wickman 2014). Rather than consider the epistemology of science as a known entity, and seeking to inculcate students into this perspective, a practical epistemology analysis focuses rather on the everyday practices of students and teachers making sense of phenomena and developing knowledge. This view takes epistemology as situated "in on-going communication, action, and practice" (Ostman and Wickman 2014, p. 375) and is consistent with the view of epistemic practices developed in this chapter. These studies examine meaning making, in situ, through analysis of the talk and action of members of a group. As the focus is on the work of deciding what counts as knowledge, the authors refer to the perspective as practical epistemologies.

Practical epistemologies focus on what counts as knowledge and how participants construct knowledge in educational events (Wickman 2004). To examine such issues in learning contexts, the researchers draw from Wittgenstein (1958) and focus on the language games of science learning. In this case, language games identify how meanings are constructed in situated actions and tied to ways of life (Heckler 2014). That is, the meanings of key terms are not taken for granted, but examined as either plausibly assumed or at stake in any given conversation. To examine practical epistemologies the research group has developed practical epistemological analysis (PEA). This approach considers those concepts that stand fast (assumed communal meaning) and the gaps (lack of initial understanding) that occur when students encounter challenges through talk or action (Wickman 2004). Students build relations with understood and effectively useful constructs across gaps in understanding. This approach allows for a close examination of how students' epistemologies in action account for the development of meaning. An example of this approach is provided by Lidar et al. (2010) who examined children's discussion about gravity and the shape of the Earth. The study showed how children made different meaning from a shared situation. These meanings were mediated by relevant artifacts such as a celestial globe and maps, and were varied in their adherence to normative interpretation.

5.3.1.2 Disciplinarity and Variation in Epistemic Practices

Science may refer to a body of knowledge, a set of disciplines, or even a way of making sense of nature. The potential for commonality and differences across different substantive disciplines remains an open question for considerations of epistemic practices. That is, we would expect commonality, at least in a family resemblance manner, for some portions of science disciplines, but also recognize that considerable variation is likely. In this section we review some of the ways that epistemic practices are manifest in various science disciplines. Our purpose is to provide illustrative examples of how different disciplines make sense of those aspects of nature studied, and what can be learned by looking across such perspectives.

The individual scientific disciplines – across the life sciences, physical sciences, and earth and space sciences – are often conveniently grouped as "science" and naively assumed to represent common ways of knowing and epistemic practices. While there may be some commonality among general epistemic practices, each of the individual sciences may require students to engage in different ways of making sense and building knowledge (Rudolph 2000). For illustrative purposes we consider some of the research around the disciplinarity in science education and examine the commonalities, but, more importantly, the differences across disciplines. Three examples make the point.

Ault (1998) used the term "domains of inquiry" in order to acknowledge that the different sciences ask different questions and use different data sets. What counts as a legitimate question, evidence, and reasoning varies according to each domain of inquiry. For example, Ault noted that the earth and space sciences seek to retrodict, or answer questions about the past, as opposed to other domains that seek to predict. What counts as data, evidence, and reasoning about past geological events differs from the data, evidence, and reasoning relevant to development of knowledge about biological organisms. Given such disciplinary differences, the epistemic practices in these domains may vary. This is evident in a set of discipline-specific criteria geology education derived by Ault (1998). To engage in geological inquiry students need to draw from specific epistemic practices such as understanding constraints on ambiguity; drawing from independent, converging lines of inquiry; identifying proper taxonomies; extrapolating systems through time; and integrating across temporal and spatial scales. This attention to domain specific epistemic practices would necessitate different pedagogical methods.

In the life sciences, Jimenez-Aleixandre (2014) sought to examine the connections between science learning and the epistemology of science and noted three interrelated dimensions: domain-general and domain-specific features of epistemologies, correct versus productive students' epistemological positions, and complementary approaches to the relationships between epistemology and science learning. Relevant to our work is her attention to domain-general versus domain-specific epistemologies, most specifically her treatment of genetics and the three aspects of relevance for engaging students: understanding what counts as acceptable science, identifying patterns in data, and recognizing the differences between probabilism and determinism. Such understandings develop through student engagement with genetics and in particular, learning to use and critique evidence through argumentation. Her argument is that the goal of teaching genetics is to support students in developing the capacity to understand and evaluate pieces of information related to genetics. Thus, building the capacity to use and evaluate evidence develops in students the abilities to learn and decipher socioscientific issues such as cloning, genetic screening, and commercial interests in genetics. This study shows how ways of engaging students in epistemic practices can develop scientific literacy in students.

Erduran (2007) and Erduran and Duschl (2004) argued for domain specific epistemological considerations in the analysis of specific features of laws in sciences and models in chemistry. Erduran (2007) made the case that laws in chemistry, such as the periodic law, are not exact and deducible in the ways that laws, such as Newton's law of gravitation, in physics are. She recommended a consideration of the application of philosophy of chemistry to chemical education in three distinct ways. First, she sought to develop ways that an epistemology of chemistry can be related to developmental patterns in students' thinking with respect to understanding how laws in chemistry are generated and evaluated. Second, she found ways that disciplinary-specific epistemology can be used to inform curriculum design. And third, epistemology of chemistry can be used to inform current and future chemistry teachers about how knowledge is structured in the discipline and how this structuring is related to the teaching of chemistry.

While epistemic practices such as argumentation and evidence-based explanations do indeed cross the boundaries of the science domains, such practices may be taken up and applied in domain specific ways that distinguish science and engineering disciplines from each other. Furthermore, the individual science subsumed under the large umbrellas of the life, physical, and earth and space sciences may also differ. Erduran (2007) made an argument noting the difference of the term "law" between chemistry and physics, both physical sciences. Similar inspection is needed in the individual life sciences (e.g. botany, zoology, mycology) as well as within earth and space science in order to consider how what counts as knowledge differs between the sciences.

5.3.1.3 Student Learning About Science Through Engagement in and with Science

One advantage of engaging students in epistemic practices of science and engineering is that they may be able to learn about the nature of the disciplines through participation. This is not to suggest that merely going through the motions of laboratory procedures develops knowledge. Rather, the processes of inquiry, reasoning, and engineering design, among other ways of knowing, offer students insights into disciplinary approaches to knowledge construction if properly organized and reflected upon (Rudolph 2000). We have argued throughout this chapter that the epistemic practices we describe are illustrative examples of the kinds of ways various science and engineering disciplines construct knowledge.

Irzik and Nola (2011) have applied Wittgenstein's notion of family resemblances to the nature of science, or more properly, the natures of the sciences. They argue that across multiple disciplines of science there is a family resemblance of the kinds of activities, values, methodologies, and products. This approach has the advantage of not limiting the nature of knowing, recognizing the value of disciplined approaches to knowledge construction, and combined with reflective practices about activities, values, methodologies, and products may improve students' understandings of and about science. Our examples of epistemic practices have largely fallen into the category of activities, but this does not mean that values, methodologies, and products do not need to be examined and integrated into education as well. Furthermore, any choice of representation of epistemic practices requires a selection of the range of real-world practices of science (Rudolph 2002).

Science learning often situates students in sense making situations, with goals of developing propositional and procedural knowledge. The focus on knowledge construction in student reasoning has led to the practical epistemology employed by students through engagement (Wickman 2004; Sandoval 2005). Wickman (2004) identified the ways that students learned what counted as a valid observation in chemistry. Students drew from the chemical phenomena, prior experience, and the expertise of the teacher. Through these processes, the students addressed gaps in their understanding by patching together meanings derived from use in the contexts of the learning situations. Sandoval (2005) took a similar approach, noting the ways that teaching about science (nature of science) has not been successful at developing robust understandings about science. He noted that engagement in inquiry does not develop an understanding about the epistemology of science. Rather, students are guided by the practical experiences of their locally relevant situation. They develop ways of knowing, or a practical epistemology, that are unlikely to be coherent and explicitly recognized by learners.

Other studies consider how students can learn about science through engagement in scientific activities. Ford (2008) drew from science studies and the psychology of learning to show how students come to understand roles as "constructors and critiquers" (p. 159) of claims. These are important roles that embody epistemic practices of scientists, and may help students take on the role of a skeptical observer. Ford is concerned with developing students' capacity to assess claims as citizens. He argued that through engagement, students develop a grasp of practice, and while this may not develop immediately into declarative knowledge about science, it can inform reasoning in the public sphere about science issues.

One important dimension of constructing and critiquing claims is the epistemic criteria brought to bear on the decisions regarding evidence. Pluta et al. (2011) examined middle school students' criteria for judging the quality of scientific models. The students were shown to be able to generate epistemic criteria such as the explanatory functions of models, the role of evidence in making decisions about uses of models, the inclusion of appropriate details in the models, and the accuracy of the models as related to empirical observations. Given the prominent role of models in scientific reasoning (Giere 1999), these criteria are important parts of learning how to engage in the construction and critique of knowledge claims.

A number of studies of epistemic practices in education consider the ways that messages about science are communicated through engagement in activity. While such messages about science may not lead to robust understandings of professional practice (Sandoval 2005), often misconceptions about science are promulgated (Lemke 1990). For example, Oliveira et al. (2012) examined teachers' uses of hedges and boosters in conversations that implied different levels of certainty in science and thus reflect an implicit view of the nature of science. As teachers often followed the stepwise progression of ideas in textbooks, students received messages about the authoritarian nature of science. In this study, the teachers' choices of how to frame knowledge and draw on only specific practices limited students' understanding of science. Interestingly, while science often publically views itself as open to revision and evidence, this value co-exists with the need to acculturate novices into the ways of being and knowing of the relevant epistemic community (Fleck 1935/1979; Kuhn 1962/1996). While messages are communicated about science through practice, across these studies and others (Akerson et al. 2000), students are shown to need reflective meta-discourse about inquiry activities to develop understandings about science (Reveles et al. 2004). Engagement in epistemic practices provides a basis for such discussions and can offer insights into the processes of knowledge construction.

5.3.1.4 Broadening Uses of Knowledge to Social and Ethical Domains

Inquiry science and socioscientific issues are two approaches to science education that have gained prominence in recent years. These approaches share a common goal in the move away from a traditional approach in which science content is delivered from the teacher to the students with little attention to how this content was produced. While both of these approaches share a common goal, the epistemic practices necessitated by each approach differ. In order to focus on the different epistemic practices promoted by these approaches, it is necessary to consider the separate goals of each approach. Goals of an inquiry approach include promoting students to ask authentic questions, plan authentic investigations, and use the results of the investigations to provide answers to the questions. As students attempt to answer a scientific question, they bring to bear scientific evidence and reasoning. Engineering education is another approach that engages students in science, but for the purposes of technical design or analysis. Across these approaches are variations in the extent of the scope of the relevant ethical domains. In inquiry science, issues of ethics and values often center on the integrity of the research approach. Engineering entails ethics around the application of design and analysis to serve a human purpose, and often the concerns are safety, function, and cost.

The goal of a socioscientific approach is to develop scientific literacy by promoting the exercise of informal reasoning in which students are compelled to analyze, evaluate, discuss, and argue varied perspectives on complex issues that are ill-structured but fundamentally important to the quality of life in social and natural spheres (Sadler 2009; Zeidler 2014). As students consider and attempt to respond to the issue at hand, they may bring scientific, ecological, moral, religious, personal, and/or economic perspectives to bear on the issue. In contrast to an inquiry science approach, a socioscientific approach does not constrain explanations, arguments, evidence, or reasoning to only a scientific perspective. In addition, a socioscientific approach often requires students to take a position on or make a decision about a specific issue. In contrasting across approaches, we can consider the concept of genetically modified organisms (GMO), in this case GMO corn. An inquiry approach might ask, "Does genetically modified corn grow better than wild corn?" On the other hand, a socioscientific issues approach might ask, "Should genetically modified corn be introduced into the natural ecosystem?" An engineering question might be "how can corn be modified to conform to a set of social and economic constraints?" While these approaches use the concept of genetically modified organisms, each asks a different question, thus promoting different epistemic practices in answering the different questions.

In considering the epistemic practices promoted by these approaches we return to the four epistemic practices of proposing, communicating, evaluating, and legitimating knowledge as proposed by Kelly (2008). While an inquiry approach focuses on the use of scientific knowledge, a socioscientific approach also considers knowledge from other domains (e.g., ethical, economic, and religious). As such, students are required to engage in epistemic practices from various perspectives, some of which may be competing. The epistemic practices foregrounded by an inquiry approach would center on the construction, communication, evaluation, and legitimization of a scientific explanation that answers a scientific question. The epistemic practices foregrounded by a socioscientific approach would require students to engage in these practices while attempting to answer the original socioscientific question that often involves taking a position. These arguments are multiple and originate from not only the scientific perspective but also ethical, moral, economic, and religious perspectives. In this way, each perspective may require students to construct, communicate, evaluate, and legitimate (or not) multiple and often competing arguments.

What counts as evidence or reasoning from each perspective may vary, thus requiring students to engage in epistemic practices that go beyond the scope of the scientific content of the argument. For example, a student arguing from the scientific perspective may provide an argument regarding the ecological implications of introducing a GMO into the natural ecosystem. On the other hand, another student may provide an argument from a purely economic perspective regarding the increased yield of GMO crops. In yet a third case, a student may provide an ethical argument stating that it is wrong to introduce an organism produced in a lab into the ecosystem. Each argument originates from a different perspective and would require students to consider what counts as a strong (or weak) argument in each of these perspectives. While both inquiry science and socioscientific issues approaches to science education promote a move away from content-delivery pedagogy, each approach differs in the epistemic practices foregrounded. Engineering provides yet another set of practices that concern identifying the problem, assessing constraints, considering multiple solutions, and providing analysis. In each of these ways of drawing from science and engaging in knowledge building require that students appropriate and take up various epistemic practices.

5.4 Characteristics of Epistemic Practice in Science and Engineering Education

Epistemic practices may be appropriated and taken up differently across a range of educational goals for STEM education. While there is no finite set of epistemic practices characterizing science or engineering, we present some illustrative examples across a range of educational goals in Table 5.2. For comparison sake we consider inquiry science (Kelly 2014b), engineering education (Cunningham and Carlsen 2014), and a socioscientific issues approach (Zeidler 2014). Some key differences in educational goals and the nature of epistemic practices are evident in

Table 5.2 Illustrative examples of epistemic practices three orientations toward science and engineering education

Disciplinary approach:	Inquiry Science	Engineering	Socioscientific issues
Epistemic practices:			
Propose	Posing scientific questions Designing scientific investigations to answer questions Making observations Envisioning relevant evidence based for an investigation Building and refining models	Identifying problems Considering problems in context Applying scientific concepts and reasoning Applying mathematical reasoning Envisioning multiple solutions Persisting and learning from failure Using systems thinking	Posing questions – scientific, economic, moral, religious, ecological Designing investigations to answer questions Balancing multiple lines of reasoning Constructing a rebuttal
Communicate	Developing a scientific line of reasoning Providing disciplinary-specific justification for knowledge claims Writing a scientific explanation (lab report) Communicating a verbal scientific explanation Constructing a scientific explanation based on evidence and reasoning	Communicating effectively in working teams Justifying project designs for given constraints Communicating to the client	Constructing evidence based on investigations Taking a position Constructing (multiple) arguments based on evidence and reasoning Presenting an argument Engaging in a debate or role-play

(continued)

Table 5.2 (continued)

Disciplinary approach:	Inquiry Science	Engineering	Socioscientific issues
Evaluate	Assessing merits of a scientific claim, evidence or model Assessing a line of scientific reasoning Evaluating scientific explanation Considering alternative explanations	Making tradeoffs between criteria and constraints Using data to drive decision making Placing value on constraints and client needs	Assessing merits of a scientific claim Evaluating evidence (what counts as evidence – moral, ethical, scientific, etc.) Assessing lines and types of reasoning Evaluating arguments holistically
Legitimize	Building group consensus for scientifically sound explanations According value to the explanation that most closely matches the preexisting scientifically accepted theories Recognizing knowledge by relevant epistemic community	Considering implications of solutions Making evidence-based decisions Acknowledging evaluation of successful technology by client	Building consensus or acceptance of the most convincing argument Recognizing value of positions taken in debate

this table. For example, inquiry science generally seeks to develop students' capacity to conduct investigations and, through this process, learn the knowledge and practices of a disciplinary community. The approach situates the students as inquirers and seeks to develop ways of building knowledge through engagement, thereby developing over time the capacity among students to make sense of their world. Engineering education focuses on developing the knowledge of design and analysis through project-based approaches that require understandings of relevant science, math, and the cultural contexts of the client. This approach finds its solution in real world applications that are optimized given a set of constraints. A socioscientific issues approach situates science in a social problem and requires that students draw from current knowledge, build on this knowledge, and apply moral and ethical reasoning to taking a position regarding a controversial issue. In each of these three orientations to learning science, there are shared and mutually exclusive epistemic practices. As previously discussed (Kelly 2016), epistemic practices are interactional, contextual, intertextual, and consequential.

Each action in the world occurs in a time and place. As these actions are developed and routinized, they can be recognized as patterns. Such patterns begin as actions members of a group take through social interaction. Engaging in social practices defines what counts as knowing and knowledge, such as proposing ideas, testing hypotheses, representing concepts, evaluating merits of candidate solutions, recognizing alternatives, justifying knowledge claims, and legitimizing conclusions (see Table 5.2). Thus, in any instance, epistemic practices are constructed in the moment, as they are *interactionally* accomplished, among people, texts, and technologies. While each interaction is situated and contextualized, participants of a group draw from common knowledge, and make reference to previous knowledge and ways of participating. Research in science education has demonstrated how discourse processes are central to knowledge construction (e.g., Kelly and Crawford 1997; Wickman 2004). The ways of talking and being, including uses of signs and symbols are characteristic of epistemic cultures (Kelly 2014a, b).

Epistemic practices are *contextualized* in time, space, social practices, and cultural norms. Knowledge is constructed through specific processes with variations across disciplines and ways of knowing (Knorr-Cetina 1999; Longino 1990). Knowledge construction occurs over time through a series of interactions from interactions around data collection, to conversations about interpretation, to forms of representation, and to processes of communication, evaluation, and legitimation (Bazerman 1988; Lynch 1992). Engaging in epistemic practices thus occurs in various venues and settings and such practices need to be examined as they occur in the making (Kelly et al. 1998). Thus, the study of epistemic practices needs to be situated in specific contexts. This suggests that the study of knowledge construction needs to occur in situ, through an examination of the processes leading to socially agreed-upon knowledge. The study on such micro-moments of interaction needs to take into consideration the ways that cultural practices are established over longer time scales and how such cultural practices enter into moments of interaction. This suggests looking across time scales to consider how epistemic practices emerge, vary, change, and influence social processes (Kelly 2008; Lemke 2000; Wortham 2003). Events constructed in the moment (e.g., a decision regarding anomalous data, consideration of ethical implications regarding a socioscientific issue) draw from contexts, practices, texts, and artifacts created at longer time scales (Goodwin 2000). For example, the genre of an experimental article in science (Bazerman 1988) becomes a cultural model that can be taken up and used to create new texts within this patterned use of language (Kelly and Bazerman 2003; Takao and Kelly 2003).

Discourse processes make use of and reference to previous discourse, both spoken and written texts, including the various signs and symbols characteristic of disciplinary knowledge, and are thus *intertextual* (Bazerman 2004; Green and Castanheira 2012). Reference to previous texts builds continuity and common knowledge as members of a social group (e.g., student laboratory group, professional research team, environmental activists) define and make use of shared assumptions of meaning (Wittgenstein 1958). Intertextuality serves as a method to identify socially salient concepts comprising common histories and cultural experiences (Vygotsky 1978). For example, students taking a stand regarding a socioscientific issue (Licona and Kelly 2015) may make reference to relevant published facts of the matter (e.g., characteristics of the ecology of an endangered species) and to definitions and policies (e.g., legal definitions). These texts serve as reference to decisions regarding how to use science to reason through a problem.

Knowledge claims are proposed, communicated, evaluated, and legitimized through social processes. Thus, epistemic practices have *consequences* for what knowledge counts for participating members of a group. Members entering into a knowledge generating culture bring ways of knowing with them that may or may not count or be recognized (Traweek 1988), as often in science and education knowledge claims need to be modified to build acknowledgement as legitimate (Kelly et al. 2001; Myers 1997). The empirical study of ways that knowledge is legitimized identifies how power, culture, and social processes are tied to what gets taken for knowledge in certain contexts (Kelly 2016).

5.5 Research Directions for the Study of Epistemic Practices in Education

We have argued that a focus on epistemic practices should be part of the pedagogy for science and engineering education across a range of educational goals. Education seeks to develop knowledge, skills, values, and ways of knowing and learning. Importantly, while substantive, conceptual knowledge plays a role in learning ways of knowing (i.e., epistemic practices depend on substantive knowledge), developing the capacity to learn and know should be a major goal of education. In this section we draw from the literature considered in previous sections of the chapter to consider plausible research directions for the study of epistemic practices in education. We propose following four directions: (a) development of learning of epistemic practices, (b) disciplinarity and learning, (c) cultural and linguistic diversity and learning epistemic practices, and (d) learning about science through engagement in practice.

A number of studies have begun to show the value of a focus on epistemic practices for science education (Manz 2014; Sandoval 2005; Wickman 2004). This positive direction opens up questions for further research. Kelly (2014b) argued that the learning of epistemic practice in science inquiry settings depends on and requires understanding of relevant concepts to the problem at hand. This means that, rather than learning domain general science process skills, students learn epistemic practices (e.g., posing questions, justifying claims) through engaging in problems where conceptual knowledge is evoked and applied. This poses research questions for the field. For example, what is the interaction of particular types of epistemic practices with substantive, disciplinary knowledge? What knowledge do students need to effectively employ epistemic practices in inquiry settings? How can the development of conceptual and epistemic knowledge co-occur and develop synergies?

We know that students bring a variety of experiences and knowledge to educational situations (González et al. 2006). These previous experiences may be resources for developing and learning epistemic practices.

Questions relevant to this topic include: What knowledge do students bring? How are students' outside of school ways of knowing relevant and helpful for developing disciplinary practices? Each learner and group of learners brings different experiences and thus offers a unique set of opportunities for learning, both for individuals within a group, but also how the group learns over time to function and become an epistemic community (Kelly 2008). Finally, there may be ways that maturation and development are related to ways that students learn to engage in epistemic practices: What are the learning progressions for epistemic practices? How can school science and engineering be designed to gauge students' development trajectories and potential?

Scholars focusing on epistemology and learning have identified the ways that disciplinary knowledge and ways of knowing vary across the sciences (Ault 1998; Erduran 2007; Jimenez-Aleixandre 2014). While often grouped together, each of the sciences, and even more so, fields of engineering, vary in the ways that they investigate and solve relevant problems in their respective fields. While we recognize these differences, and acknowledge that such differences should not be glossed, science teachers face the problem of developing the knowledge, inquiry abilities, values, and applications of science and engineering in real settings. Furthermore, nuances in disciplinarity may be lost on students. This poses a number of research questions about disciplinarity and learning: What are the ways that understandings about the sciences and engineering fields can be refined through empirical inquiry? How is knowledge gained about such practices relevant to teaching? To what extent do students learn to transfer epistemic practices gained in one discipline (e.g., recognizing anomalies to a distribution of data) to another discipline with different substantive knowledge (e.g., epidemiology and atmospheric sciences)?

We live in an increasingly multilingual and multicultural world. Different ways of knowing offer opportunities to learn about and draw from alternative ways of making sense and learning (Varelas et al. 2008; Varelas et al. 2012). Students bring ways of sense making to educational events that can be drawn into school activities, thus serving as resources for learning. Furthemore, various sciences produce their own cultural ways of being with particular ways of communicating, producing knowledge, and being a member of the group (Knorr-Cetina 1999; Watson-Verran and Turnbull 1995). Thus, learning science or engineering can be viewed as a process of acculturation in which new members both learn the extant ways of being and doing, but also transform the current practice through innovation and change. Research questions emerging from this area include: What sorts of ways of knowing do students bring to educational events? How can these ways of knowing contribute? How can access to the practices of epistemic cultures be made visible and opened to learners?

Finally, engaging in epistemic practices offers contexts for discussion and reflection about science and engineering fields (Akerson et al. 2000; Kelly 2014a, b). While it is generally recognized that merely engaging in activity does not produce propositional knowledge about science (Abd-El-Khalick 2012; Sandoval 2005), learning to propose, communicate, evaluate, and legitimize knowledge claims can provide a basis for discussions, reflection, and further reading about how science and engineering operate, the values in these disciplines, and limitations of these ways of approaching problems. Research in these areas may consider the following questions: What are the relationships between competency in certain epistemic practices and learning science and engineering? How are epistemic practices generative of new knowledge of and about science and engineering? What sorts of engagement and reflection leads to learning of and about science and engineering that support decision making for socioscientific issues?

5.6 Conclusion

Our argument in this chapter is that engagement in epistemic practices is an important part of a robust science education. Part of the need to engage in epistemic practices is to learn values of knowledge-producing communities – the value of persuasion over force, open-mindedness over dogma, and consideration of alternative solutions, and so forth (Rorty 1991). Scientific explanation and argument are not technical procedures, as they do not have specific formulas that can be translated easily to the pedagogy of science education. We drew from three types of educational approaches (inquiry, engineering, socioscientific issues), each with different goals, to identify illustrative examples of epistemic practices across these contexts. Each of these approaches can support goals for scientific literacy, suggested by Aikenhead et al. (2011): developing the capacity to engage with issues from a scientific perspective. Central to such engagement is an understanding of the disciplinary ways of proposing, communicating, evaluating, and legitimizing knowledge claims. Through such engagement, connected to carefully organized pedagogy, students may build capacity to participate as informed citizens in the public sphere.

References

Abd-El-Khalick, F. (2012). Examining the sources for our understandings about science: Enduring conflations and critical issues in research on nature of science in science education. *International Journal of Science Education, 34*, 353–374.

Aikenhead, G., Orpwood, G., & Fensham, P. (2011). Scientific literacy for a knowledge society. In C. Linder, L. Östman, D. A. Roberts, P. Wickman, G. Erikson, & A. McKinnon (Eds.), *Exploring the landscape of scientific literacy* (pp. 28–44). New York: Routledge.

Akerson, V. L., Abd-El-Khalick, F., & Lederman, N. G. (2000). Influence of a reflective explicit activity-based approach on elementary teachers' conceptions of nature of science. *Journal of Research in Science Teaching, 37*, 295–317.

Allchin, D. (2004). Should the sociology of science be rated X? *Science Education, 88*, 1–13.

Allchin, D. (2011). Evaluating knowledge of the nature of (whole) science. *Science Education, 95*, 518–542.

Ault, C. R. (1998). Criteria of excellence for geological inquiry: The necessity of ambiguity. *Journal of Research in Science Teaching, 35*, 189–212.

Bazerman, C. (1988). *Shaping written knowledge: The genre and activity of the experimental article in science*. Madison: University of Wisconsin Press.

Bazerman, C. (2004). Intertextualities: Volosinov, Bakhtin, literary theory, and literacy studies. In A. F. Ball & S. Warshauer Freedman (Eds.), *Bakhtinian perspectives on language, literacy, and learning* (pp. 53–65). Cambridge: Cambridge University Press.

Collins, H. M. (1985). *Changing order: Replication and induction in scientific practice*. London: Sage.

Collins, H. M. (2007). The uses of sociology of science for scientists and educators. *Science & Education, 16*, 217–230.

Collins, H. M. (2014). *Are we all scientific experts now?* New York: John Wiley & Sons.

Cunningham, C. M., & Carlsen, W. S. (2014). Precollege engineering education. In N. G. Lederman & S. K. Abell (Eds.), *Handbook of research on science education* (Vol. 2, pp. 747–758). Mahwah: Lawrence Erlbaum Associates.

DeBoer, G. E. (2000). Scientific literacy: Another look at its historical and contemporary meanings and its relationship to science education reform. *Journal of Research in Science Teaching, 37*(6), 582–601.

Duschl, R. A. (1990). *Restructuring science education: The importance of theories and their development*. New York: Teacher's College Press.

Duschl, R. A. (2008). Science education in three-part harmony: Balancing conceptual, epistemic, and social learning goals. *Review of Research in Education, 32*, 268–291.

Duschl, R., & Grandy, R. (2008). Consensus: Expanding the scientific method and school science. In R. Duschl & R. Grandy (Eds.), *Teaching scientific inquiry: Recommendations for research and implementation* (pp. 304–325). Rotterdam: Sense Publishers.

Erduran, S. (2007). Breaking the law: Promoting domain-specificity in chemical education in the context of arguing about the periodic law. *Foundations of Chemistry, 9*(3), 247–263.

Erduran, S., & Duschl, R. A. (2004). Interdisciplinary characteristics of models and the nature of chemical knowledge in the classroom. *Studies in Science Education, 40*, 105–138.

Fleck, L. (1935/1979). Genesis and development of a scientific fact. (F. Bradley & T. J. Trenn, Trans.). Chicago: University of Chicago Press.

Ford, M. (2008). Disciplinary authority and accountability in scientific practice and learning. *Science Education, 92*, 404–423.

Garfinkel, H., Lynch, M., & Livingston, E. (1981). The work of discovering science construed with materials from the optically discovered pulsar. *Philosophy of the Social Sciences, 11*, 131–158.

Giere, R. (1999). *Science without laws*. Chicago: University of Chicago Press.

González, N., Moll, L. C., & Amanti, C. (Eds.). (2006). *Funds of knowledge: Theorizing practices in households, communities, and classrooms*. New York: Routledge.

Goodwin, C. (2000). Action and embodiment within situated human interaction. *Journal of Pragmatics, 32*, 1489–1522.

Green, J., & Castanheira, M. L. (2012). Exploring classroom life and student learning: An interactional ethnographic approach. In B. Kaur (Ed.), *Understanding teaching and learning: Classroom research revisited* (pp. 53–65). Rotterdam: Sense.

Green, J. L., Weade, R., & Graham, K. (1988). Lesson construction and student participation: A sociolinguistic analysis. In J. L. Green & J. O. Harker (Eds.), *Multiple perspective analyses of classroom discourse*. Norwood: Ablex.

Gross, A. (1989). *The rhetoric of science*. Cambridge, MA: Harvard University Press.

Gumperz, J. J. (2001). Interactional sociolinguistics: A personal perspective. In D. Schiffrin, D. Tannen, & H. E. Hamilton (Eds.), *Handbook of discourse analysis* (pp. 215–228). Malden: Blackwell.

Heckler, W. S. (2014). Research on student learning in science: A Wittgensteinian perspective. In M. Matthews (Ed.), *International handbook of research in history, philosophy and science teaching* (pp. 1381–1410). Dordrecht: Springer.

Irzik, G., & Nola, R. (2011). A family resemblance approach to the nature of science for science education. *Science & Education, 20*, 591–607.

Jiménez-Aleixandre, M. P. (2014). Determinism and underdetermination in genetics: Implications for students' engagement in argumentation and epistemic practices. *Science & Education, 23*, 465–484.

Kelly, G. J. (2005). Discourse, description, and science education. In R. Yerrick & W.-M. Roth (Eds.), *Establishing scientific classroom discourse communities: Multiple voices of research on teaching and learning* (pp. 79–108). Mahwah: Lawrence Erlbaum Associates.

Kelly, G. J. (2008). Inquiry, activity, and epistemic practice. In R. Duschl & R. Grandy (Eds.) *Teaching scientific inquiry: Recommendations for research and implementation* (pp. 99–117; 288–291). Rotterdam: Sense Publishers.

Kelly, G. J. (2011). Scientific literacy, discourse, and epistemic practices. In C. Linder, L. Östman, D. A. Roberts, P. Wickman, G. Erikson, & A. McKinnon (Eds.), *Exploring the landscape of scientific literacy* (pp. 61–73). New York: Routledge.

Kelly, G. J. (2014a). Discourse practices in science learning and teaching. In N. G. Lederman & S. K. Abell (Eds.), *Handbook of research on science education, volume 2* (pp. 321–336). Mahwah: Lawrence Erlbaum Associates.

Kelly, G. J. (2014b). Inquiry teaching and learning: Philosophical considerations. In M. Matthews (Ed.), *International handbook of research in history, philosophy and science teaching* (pp. 1363–1380). Dordrecht: Springer.

Kelly, G. J. (2016). Methodological considerations for the study of epistemic cognition in practice. In J. A. Greene, W. A. Sandoval, & I. Braten (Eds.), *Handbook of epistemic cognition* (pp. 393–408). New York: Routledge.

Kelly, G. J., & Bazerman, C. (2003). How students argue scientific claims: A rhetorical-semantic analysis. *Applied Linguistics, 24*(1), 28–55.

Kelly, G. J., & Brown, C. M. (2003). Communicative demands of learning science through technological design: Third grade students' construction of solar energy devices. *Linguistics & Education, 13*(4), 483–532.

Kelly, G. J., & Crawford, T. (1997). An ethnographic investigation of the discourse processes of school science. *Science Education, 81*(5), 533–559.

Kelly, G. J., & Green, J. (1998). The social nature of knowing: Toward a sociocultural perspective on conceptual change and knowledge construction. In B. Guzzetti & C. Hynd (Eds.), *Perspectives on conceptual change: Multiple ways to understand knowing and learning in a complex world* (pp. 145–181). Mahwah: Lawrence Erlbaum Associates.

Kelly, G. J., Carlsen, W. S., & Cunningham, C. M. (1993). Science education in sociocultural context: Perspectives from the sociology of science. *Science Education, 77*, 207–220.

Kelly, G. J., Chen, C., & Crawford, T. (1998). Methodological considerations for studying science-in-the-making in educational settings. *Research in Science Education, 28*(1), 23–49.

Kelly, G. J., Crawford, T., & Green, J. (2001). Common tasks and uncommon knowledge: Dissenting voices in the discursive construction of physics across small laboratory groups. *Linguistics & Education, 12*(2), 135–174.

Kelly, G. J., McDonald, S., & Wickman, P. O. (2012). Science learning and epistemology. In K. Tobin, B. Fraser, & C. McRobbie (Eds.), *Second international handbook of science education* (pp. 281–291). Dordrecht: Springer.

Knorr-Cetina, K. (1995). Laboratory studies: The cultural approach to the study of science. In S. Jasanoff, G. E. Markle, J. C. Peterson, & T. Pinch (Eds.), *Handbook of science and technology studies* (pp. 140–166). Thousand Oaks: Sage.

Knorr-Cetina, K. (1999). *Epistemic cultures: How the sciences make knowledge*. Cambridge, MA: Harvard University Press.

Koertge, N. (1998). Postmodernisms and the problem of scientific literacy. In N. Koertge (Ed.), *A house built on sand: Exposing postmodern myths about science* (pp. 257–271). New York: Oxford University Press.

Kuhn, T. S. (1962/1996). *The structure of scientific revolutions* (3rd ed.). Chicago: University of Chicago Press.

Kuhn, D. (1992). Thinking as argument. *Harvard Educational Review, 62*(2), 155–178.
Latour, B. (1987). *Science in action: How to follow scientists and engineers through society*. Cambridge, MA: Harvard University Press.
Leach, J., & Scott, P. (2003). Individual and sociocultural views of learning in science education. *Science & Education, 12*, 91–113.
Lead States, N. G. S. S. (2013). *Next Generation Science Standards: For States, By States*. Washington, DC: The National Academies Press.
Lehrer, R., & Schauble, L. (2012). Seeding evolutionary thinking by engaging children in modeling its foundations. *Science Education, 96*, 701–724.
Lemke, J. L. (1990). *Talking science: Language, learning and values*. Norwood: Ablex.
Lemke, J. L. (2000). Across the scales of time: Artifacts, activities, and meanings in ecosocial systems. *Mind, Culture, and Activity, 7*(4), 273–290.
Licona, P. & Kelly, G. J. (2015, April). *Arguing from evidence in an English/Spanish dual language middle school science classroom*. Paper presented at the annual meeting of the NARST. Chicago, IL.
Lidar, M., Almqvist, J., & Ostman, L. (2010). A pragmatist approach to meaning making in children's discussions about gravity and the shape of the earth. *Science Education, 94*, 689–709.
Longino, H. E. (1990). *Science as social knowledge: Values and objectivity in science inquiry*. Princeton: Princeton University Press.
Longino, H. E. (1993). Subjects, power, and knowledge: Description and prescription in feminist philosophies of science. In L. Alcoff & E. Potter (Eds.), *Feminist Epistemologies* (pp. 101–120). New York: Routledge.
Longino, H. E. (2002). *The fate of knowledge*. Princeton: Princeton University Press.
Lynch, M. (1992). Extending Wittgenstein: The pivotal move from epistemology to the sociology of science. In A. Pickering (Ed.), *Science as practice and culture* (pp. 215–265). Chicago: University of Chicago Press.
Manz, E. (2014). Representing student argumentation as functionally emergent from scientific activity. *Review of Educational Research*.
Matthews, M. (Ed.). (2014). *International handbook of research in history, philosophy and science teaching*. Dordrecht: Springer.
Matthews, M. (2015). *Science teaching: The contribution of history and philosophy of science, 20th anniversary revised and* (expanded ed.). New York: Routledge.
McDonald, S., & Songer, N. B. (2008). Enacting classroom inquiry: Theorizing teachers' conceptions of science teaching. *Science Education, 92*, 973–993.
Myers, G. (1989). The pragmatics of politeness in scientific articles. *Applied Linguistics, 10*, 1–35.
Myers, G. (1997). Texts as knowledge claims: The social construction of two biology articles. In R. A. Harris (Ed.), *Landmark essay on the rhetoric of science: Case studies* (pp. 187–215). Mahwah: Erlbaum.
Norman, A. (1998). Seeing, semantics and social epistemic practice. *Studies in the History and Philosophy of Science, 29*, 501–513.
Norris, S. P., & Phillips, L. M. (2003). How literacy in its fundamental sense is central to scientific literacy. *Science Education, 87*, 224–240.
Norris, S., Phillips, L. M., & Burns, D. P. (2014). Conceptions of scientific literacy: Identifying and evaluating their programmatic elements. In M. Matthews (Ed.), *International handbook of research in history, philosophy and science teaching* (pp. 1317–1344). Dordrecht: Springer.
Oliveira, A. W., Akerson, V. L., Colak, H., Pongsanon, K., & Genel, A. (2012). The implicit communication of nature of science and epistemology during inquiry discussion. *Science Education, 96*, 652–684.
Ostman, L., & Wickman, P.-O. (2014). A pragmatic approach on epistemology, teaching, and learning. *Science Education, 98*, 375–382.
Pinch, T. (1986). *Confronting nature*. Dordrecht: R. Reidel.
Pluta, W. J., Chinn, C. A., & Duncan, R. G. (2011). Learners' epistemic criteria for good scientific models. *Journal of Research in Science Teaching, 48*, 486–511.

Reveles, J. M., Cordova, R., & Kelly, G. J. (2004). Science literacy and academic identity formulation. *Journal for Research in Science Teaching, 41*, 1111–1144.
Rorty, R. (1991). *Objectivity, relativism, and truth*. New York: Cambridge University Press.
Roth, W. M., McGinn, M. K., & Bowen, G. M. (1996). Applications of science and technology studies: Effecting change in science education. *Science, Technology & Human Values, 21*, 454–484.
Rudolph, J. L. (2000). Reconsidering the 'nature of science' as a curriculum component. *Journal of Curriculum Studies, 32*, 403–419.
Rudolph, J. L. (2002). Portraying epistemology: School science in historical context. *Science Education, 87*, 64–79.
Sadler, T. D. (2004). Informal reasoning regarding socioscientific issues: A critical review of research. *Journal of Research in Science Teaching, 41*, 513–536.
Sadler, T. D. (2009). Situated learning in science education: Socio-scientific issues as contexts for practice. *Studies in Science Education, 45*(1), 1–42.
Saljo, R. (2012). Literacy, digital literacy and epistemic practices: The co-evolution of hybrid minds and external memory systems. *Nordic Journal of Digital Literacy, 7*(1), 5–19.
Sandoval, W. A. (2005). Understanding students' practical epistemologies and their influence on learning through inquiry. *Science Education, 89*, 634–656.
Slezak, P. (1994a). Sociology of science and science education: Part I. *Science & Education, 3*(3), 265–294.
Slezak, P. (1994b). Sociology of science and science education. Part 11: Laboratory life under the microscope. *Science & Education, 3*(4), 329–356.
Stewart, J., & Rudolph, J. L. (2001). Considering the nature of scientific problems when designing science curricula. *Science Education, 85*, 207–222.
Takao, A. Y., & Kelly, G. J. (2003). Assessment of evidence in university students' scientific writing. *Science & Education, 12*, 341–363.
Toulmin, S. (1972). *Human understanding* (Vol. 1: The collective use and evolution of concepts). Princeton: Princeton University Press.
Traweek, S. (1988). *Beamtimes and lifetimes: The world of high energy physicists*. Cambridge, MA: Harvard University Press.
Varelas, M., Pappas, C. C., Kane, J. M., Arsenault, A., Hankes, J., & Cowan, B. M. (2008). Urban primary-grade children think and talk science: Curricular and instructional practices that nurture participation and argumentation. *Science Education, 92*, 65–95.
Varelas, M., Kane, J. M., & Wylie, C. D. (2012). Young black children and science: Chronotopes of narratives around their science journals. *Journal of Research in Science Teaching, 49*, 568–596.
Vygotsky, L. (1978). *Mind in society: The development of higher psychological processes*. Cambridge, MA: Harvard.
Watson-Verran, H., & Turnbull, D. (1995). Science and other indigenous knowledge systems. In S. Jasanoff, G. E. Markle, J. C. Peterson, & T. Pinch (Eds.), *Handbook of science and technology studies* (pp. 115–139). Sage: Thousand Oaks.
Wickman, P.-O. (2004). The practical epistemologies of the classroom: A study of laboratory work. *Science Education, 88*, 325–344.
Wittgenstein, L. (1958). Philosophical investigations (3rd ed.). (G. E. M. Anscombe, Trans.). New York: Macmillan Publishing.
Wortham, S. (2003). Curriculum as a resource for the development of social identity. *Sociology of Education, 76*, 229–247.
Zeidler, D. L. (2014). Socioscientific issues as a curriculum emphasis. In N. G. Lederman & S. K. Abell (Eds.), *Handbook of research on science education* (Vol. 2, pp. 697–726). Mahwah: Lawrence Erlbaum Associates.

Chapter 6
Strategies for Learning Nature of Science Knowledge: A Perspective from Educational Psychology

Erin E. Peters-Burton

6.1 Introduction

Learning how to think scientifically is an important skill for citizens in modern democratic states, and perhaps even more importantly in authoritarian states where serious and critical thinking is not encouraged. In order to have a democratic community of people who can make knowledgeable decisions, citizens need to be able to evaluate the reliability of evidence and be able to use logic and reason, particularly when voting on scientific issues but on many other matters as well. This paper examines parallels between nature of science instruction and the processes explained by self-regulated learning theory, with a particular emphasis on the extension of effective strategies for learners which can be enhanced by the use of self-regulated learning cycles in a classroom setting.

6.2 Influence of Epistemological Stance on Science Learning

Epistemic cognition is the foundation for scientific thinking. Formal scientific epistemologies are those that express beliefs about how knowledge is generated by professionals in science which can be derived from the activities within a discipline (Sandoval 2005; Knorr-Cetina 1999). Practical epistemologies consist of beliefs that organize the ideas students have about the natural world. This paper focuses on ways to develop student practical epistemologies so that they are more aligned with formal scientific epistemologies. Over 20 years of accumulated evidence has demonstrated that a person's own epistemology plays a role in developing reasoning, connecting evidence and claims, and setting the foundation for learning

E.E. Peters-Burton (✉)
College of Education, George Mason University, Fairfax, VA, USA
e-mail: epeters1@gmu.edu

M.R. Matthews (ed.), *History, Philosophy and Science Teaching*, Science: Philosophy, History and Education, DOI 10.1007/978-3-319-62616-1_6

approaches.[1] Students' views of their understanding of science are often not influenced until they examine their own scientific epistemology (Kalman 2009). Further, supporting the growth of epistemological understandings can improve student scientific conceptions (Monk and Osborne 1997) and expand a student's scientific mindset (Kalman and Aulls 2003).

The ways that curriculum materials communicate an epistemic stance are also influential in supporting learning in science. The choices made by curriculum designers in communicating the epistemological authenticity in the activities have influence over the student epistemologies developed during the lessons (Chinn and Malhotra 2002). Curriculum materials that clearly communicate the epistemic stance of the activity by explaining the purposes of investigations have led to well-designed student investigations (Schauble et al. 1995) and more systematic explanations of investigation results by students (Dunbar 1993). Conversely, simply engaging in inquiry may not be sufficient to develop ideas about the nature of science.[2] Because it is important to actively engage student epistemological orientation, curriculum materials must communicate well-informed epistemic stances in science to promote continued learning in science. Students studying maths who believe that knowledge is a collection of isolated facts that must be given to them by an authority that will never change will most likely have shallow strategies for learning and little ability to think critically (Muis 2004). Students who are aware of their constructivist epistemic cognition have deeper processing strategies in learning (Muis 2004).

6.3 Views of NOS for Curricular Purposes

Although there is some disagreement among philosophers of science about what ideas comprise the nature of science (Alters 1997), there is considerable agreement among science curriculum reform documents in the United States, Canada, United Kingdom, Australia, and New Zealand about what NOS views should be included in the curriculum (McComas et al. 2009). Osborne et al. (2003) conducted a study to determine the agreement of scientists, historians, philosophers, and sociologists about what ideas about science should be taught in schools. The themes found in this study are resonant with the science education reform documents analyzed by McComas and Olson (1998): scientific method and critical testing, creativity, historical development of scientific knowledge, science and questioning, diversity of scientific thinking, analysis and interpretation of data, science and certainty, hypothesis and prediction, and collaboration (Osborne et al. 2003). These themes are also similar to the aspects of NOS employed by Lederman et al. (2014) and colleagues. However, more recently these consensus lists have been criticized for being oversimplified (Clough 2007) and for not representing NOS as contextual and heterogeneous features of science (Matthews 2012). Hodson (2014), Allchin (2011), and Irzik and

[1] Hofer and Pintritch (2002), King and Kitchener (1994), Kuhn (1999), Tsai (2000).

[2] Khishfe and Abd-El-Khalick (2002), Meichtry (1992), Sandoval and Morrison (2003).

Nola (2014) have called for revisions that would broaden the view of nature of science knowledge, keeping what is relevant from the consensus lists (such as rigorous testing) while embracing new concepts of science (such as sociocultural dynamics). The Family Resemblance Approach (Erduran and Dagher 2014) further consolidates epistemic, cognitive, and social aspects into a holistic model that characterizes science as a “range of practices, methodologies, aims and values, and social norms that have to be acknowledged when teaching science” (p. 19). As shifts occur in the conceptualization of the nature or features of science, it becomes even more imperative to consider the implications of how students may learn these constructs. The model for learning NOS proposed in this paper is responsive to the configuration of NOS as broad contextualized understanding of NOS, NOS approaches that help students demarcate what is science and what is not science (Smith and Scharmann 2008), and those that are more performance based (see Irzik and Nola 2014).

Augmenting typical content instruction with nature of science knowledge can add to the intrinsic value of the course, generate student interest, and equip students to make decisions regarding socio-scientific issues (Driver et al. 1996). To more faithfully represent the scientific discipline to students, teachers must know what constitutes an authentic view of scientific practices, such as those outlined in the Next Generation Science Standards, and how this view can be effectively communicated to students (Wong and Hodson 2009). However, many science teachers do not have adequate knowledge about the discipline or are not familiar with a scientist (Hogan 2000), and they must rely on curriculum materials to communicate NOS. This situation is complicated because curricular materials and textbooks often portray the discipline of science as stereotypical (Hodson 1993; McComas 2008), such as portraying a singular way scientists investigate questions as a rigid step-by-step progression through *the* scientific method. Another difficulty for teachers teaching about NOS effectively is that some teachers may regard NOS standards as discrete list of components and not demonstrate the interaction of the aspects of NOS because of their limited exposure to the scientific discipline. Additionally, it is a concern that teachers may teach aspects of NOS in a solely decontextualized fashion, such as presenting the model of the tentativeness of science as a puzzle without addressing any authentic situations in science where there are competing theories (Allchin 2011). Given the various science education reforms that include a focus on NOS, it is clear that teaching and learning the nature of science in elementary and secondary classrooms is valued. However, there are still many unresolved issues in both the areas of teaching and learning science as a way of knowing effectively for students in the K-12 arena.

6.4 Effective Teaching of NOS Knowledge

An examination of the efforts to create NOS-friendly curriculum for the past 50 years can give insight to how we understand effective teaching of NOS knowledge. The curricula that were developed in the 1960s and 1970s in the United States through

National Science Foundation funding, such as the Physical Science Study Curriculum (PSSC) and the Biological Sciences Curriculum Study (BSCS), supported student learning using hands-on methods and science process skills, through which it was believed students could learn NOS implicitly by engaging in science activities without any reference to the rationale of the choices made in an investigation (Lawson 1982; Rudolph 2002). However, comparative studies of student outcomes demonstrated that students who participated in the PSSC curricula had similar views of NOS as compared to traditional textbook orientated courses (Trent 1965). Jungwirth (1970) found that students participating in the BSCS Yellow curricula also did not have an enhanced view of NOS when compared with students in traditional biology programmes. More studies using a variety of measures of NOS knowledge continued to show the same results. Tamir (1972) conducted a large-scale study using BSCS Yellow, PSSC, and traditional science courses as treatment conditions across 44 different high schools with approximately 3500 students and found no significant differences in NOS views across the three treatments. In 1992, Meichtry found that students engaged in the BSCS curricula actually had several NOS understandings that were less informed as compared with students in a traditional class, with an overall result of no differences in NOS views. Overwhelming evidence has demonstrated that teaching NOS implicitly through hands-on science activities or inquiry lessons and expecting students to notice particular epistemic stances is not effective.

6.5 Defining Explicit and Reflective Approaches

This section reviews the literature regarding the description of explicit and reflective NOS approaches within science education interventions and is the first step in analyzing cognitive processes which will lead to a more systematic evaluation of effective strategies. Explicit instruction of NOS involves "cognitive instructional outcomes that should be intentionally targeted and planned for in the same manner that abstract understandings associated with high-level scientific theories are intentionally targeted" (Khishfe and Abd-El-Khalick 2002, p. 555). Several NOS researchers describe an explicit instructional approach as one that deliberately focuses learners' attention on various aspects of NOS during classroom instruction, discussion, and questioning.[3] Duschl and Grandy (2012) further distinguish two versions of explicit instruction of NOS. Version 1 being taught as "explicit references to a set of heuristic principles that philosophers and historians of science use to characterize science as a way of knowing" (p. 3) and Version 2, which they advocate, "conceptualized in terms of cognitive, epistemic, and social practices and the material and technological contexts that characterize doing science" (p. 3).

Reflective instructional elements have been defined in the NOS literature as "providing students with opportunities to analyze the activities in which they are engaged from various perspectives (e.g., a NOS framework), to map connections between

[3] Akerson and Volrich (2006), Bell et al. (2011), Khishfe (2012), McDonald (2010).

their activities and ones undertaken by others (e.g., scientists), and to draw generalizations about a domain of knowledge (e.g., epistemology of science)" (Khishfe and Abd-El-Khalick 2002, p. 555). In a more holistic description of reflective approaches to NOS, Abd-El-Khalick and Lederman (2000) explain that "reflective elements are designed to emulate the sort of activities that historians, philosophers, and sociologists engage in their efforts to understand the workings of science" (p. 691). Likewise, Scharmann et al. (2005) believe reflective instruction should challenge learners to think about how their work illustrates NOS and how their inquiries are similar to or different from the work of scientists. Although the terms "explicit" and "reflective" have been described in the science education literature and some descriptions of explicit and reflective approaches on specific subject matter have enough detail to be replicated (Rudge and Howe 2009), most descriptions are very general and difficult to operationalize for systematic use in classrooms.

6.6 Explicit and Reflective Approaches to NOS Instruction

Due to the lack of impact of implicit methods on student learning of NOS, science educators and researchers turned to an explicit means of teaching NOS, in which intentionally selected events in science instruction are emphasized as a feature of the discipline of science (Akindehin 1988). A shift from the passive, implicit methods to more explicit methods of attention focusing showed promise in changing student views of NOS (Billeh and Hasan 1975; Ogunnivi 1983). Since it was becoming apparent that students would not be able to learn NOS understandings from the environment in which they engaged but could be successful when teachers directed their attention to particular ways the discipline of science was conducted, an emphasis on teacher understanding of NOS became prominent (Akerson et al. 2000). These studies showed that an explicit approach in teacher professional development was more effective than an implicit approach in creating more sophisticated views of NOS with both in-service and pre-service teachers,[4] building evidence for choosing explicit methods as an effective instructional tool for teaching NOS. An additional component of instruction, a reflective approach to NOS instruction was added to the explicit approaches, which emphasized that the learner describes their understanding of NOS after they learn through explicit methods.[5] The focus on teaching through explicit and reflective methods has shown promise in shifting views of NOS to be more sophisticated. Note that this paper refers to these methods as explicit and reflective, whereas much of the prior research refers to these methods as explicit, reflective. The separation of the components is intentional because each approach is considered a different process for the purposes of this paper.

[4] Abd-El-Khalick and Lederman (2000), Akerson and Hanuscin (2007), Hanuscin et al. (2006), Khishfe (2008), Scharmann et al. (2005), Schwartz et al. (2004).

[5] Abd-El-Khalick (2005), Abd-El-Khalick and Akerson (2004), Abd-El-Khalick et al. (1998).

Although explicit and reflective methods have garnered improved outcomes in NOS views for both teachers and students, these methods are not effective for all students nor are they effective in encouraging the retention views over time for all learners. For example, Leach et al. (2003) found that students aged 9–16 were not able to use a logical, comprehensive evaluation of the relationship between explanation and theory in their study. Morrison et al. (2009) compared elementary and secondary teacher change in their NOS views after a professional development and found that secondary teachers with previous experience with research did not change their views of scientists or NOS, but elementary teachers did. Perhaps the most prominent limitation in changing NOS views is the difficulty that teachers who have even a more sophisticated NOS view after instruction have difficulty translating their own knowledge into their classroom practice.[6] Explicit methods have been fruitful but not overwhelmingly successful. Therefore, finding ways to teach NOS effectively is needed. The purpose of this paper is to address parallels between science education research on explicit and reflective approaches and processes in educational psychology research on self-regulated learning theory. Because self-regulated learning theory has more articulated processes of learning and motivation than those currently described in explicit/reflective NOS instruction, adoption of a self-regulated learning orientated framework offers more distinct methods of measuring processes of learners engaged in NOS instruction.

6.7 A Focus on Student Learning in NOS

A difficulty with current approaches for explicit and reflective NOS instruction in the literature is that they communicate a direction for the teacher, but do not indicate the strategies that the student should be incorporating to enhance NOS learning. This is problematic, because it does not give guidance to the learner about productive approaches and does not consider possibilities for learners to self-direct and ultimately be life-long learners about scientific developments in knowledge. Descriptions of lessons in NOS focus on how the teacher should design the lessons which are ultimately student-centered, but do not provide information about how the student should learn NOS. What types of strategies, cognition, metacognition, and behaviors should students have to take on responsibility for learning? Good learning theory can help to answer this question.

[6] Abd-El-Khalick et al. (1998), Abd-El-Khalick and Akerson (2004), Akerson et al. (2000).

6.8 Useful Learning Strategies from Educational Psychology

Because the descriptions of explicit and reflective NOS instructional methods from the literature consist of directions for the teacher and not for the student, there is a need to explain how students should be interacting with the teacher and curriculum materials to support NOS learning. Since the purpose of this paper is to build an approach for how students learn NOS from the foundation of the teacher directions given in current explicit and reflective approaches, self-regulated learning theory (SRL) is a useful lens from which to examine student learning processes (Zimmerman 2000). Self-regulated learning theory describes how learners react to their learning environment with their currently held beliefs, values, knowledge, motivation, and metacognitive strategies. According to SRL, individuals are not merely passive players in the learning process; rather, through development of personal perceptions of efficacy, they have the potential to exert personal agency and control over their learning goals along with their behaviors, emotions, and environments that lead to these goals (Bandura 2001; Zimmerman 2000). SRL has been used to improve achievement in diverse areas such as use of instructional media (Henderson 1986), volleyball skills (Zimmerman and Kitsantas 2002), and science instruction (Cleary and Labuhn 2013). In addition there are emerging studies that demonstrate the use of an SRL-based intervention can improve NOS knowledge (Peters and Kitsantas 2010b; Peters 2012), teaching using inquiry (Peters-Burton 2013), and teaching using argumentation (Peters-Burton 2013).

6.9 Self-Regulated Learning Theory

Students who exhibit proactive, goal-directed and strategic behaviors, high levels of self-awareness, and efficient reflection and adaptation skills are typically referred to as sophisticated self-regulated learners (Zimmerman 2000). These students are driven, have many strategies from which to solve problems, seek help efficiently and effectively, and persist even when they face a challenge. Self-regulated students are able to self-direct their behaviors to overcome personal challenges presented by these activities, and they will often need minimal supports or feedback from teachers or other adults (Zimmerman 2000). Specifically in science education, researchers have argued that effective instruction should not only increase learning of scientific topics, it should help to nurture the motivation, strategic behaviors and thinking, and metacognitive skills of students, particularly as they progress through middle and high school contexts (Peters and Kitsantas 2010a; Sinatra and Taasoobshirazi 2011). Several studies have investigated the effects of self-regulatory interventions incorporating key SRL subprocesses on the science achievement of school-aged students (Cleary and Labuhn 2013; Peters 2012; Peters and Kitsantas 2010b).

Collectively, these studies show that when SRL subprocesses, such as planning, metacognitive monitoring and self-evaluation, are incorporated into classroom or tutoring activities, they are effective in developing science content knowledge and scientific thinking practices. Although the processes are controlled by the student, the teacher can establish an environment, model behaviors, and prompt students to think about key characteristics of their learning. Beginning from a foundation of the current explicit and reflective NOS approaches explained in the literature, this paper demonstrates ways self-regulated learning theory can be used to describe advantageous learning processes for students engaging in learning about NOS.

6.10 Subprocesses of the Phases of Self-Regulated Learning

Zimmerman (2000) defined three phases in the SRL model: forethought, performance, and self-reflection, which occur temporally around a defined learning task. The *forethought phase* requires that students organize the content and skills they already know about the learning task (e.g., how scientists determine what is empirical), consider how much they value the learning task, and assess their level of comfort in tackling the learning task. The *performance phase* includes processes that occur during the action, such as implementation of the task and self-monitoring against a standard for the field (e.g., considering if the link between claims and evidence constitutes validity and reliability). The *self-reflection phase* refers to the processes that occur after the performance efforts which influence a learner's response to the action such as the self-judgments about feedback given on the performance (e.g., students compare external feedback to their internal judgment of the performance) and to what they attribute their successes or failures. Within the three phases of self-regulated learning theory, there are a total of 12 subprocesses as shown in Fig. 6.1 that have been empirically identified. The definitions for each subprocess can be found in Table 6.1. Because students continue to cycle through the SRL feedback loops, when students enter successive iterations of the loop that yield cognition and behaviors that lead to improved learning, they have more sophisticated forethought, performance, and self-reflection processes.

Feedback, which is designed to reduce gaps between what student can do or know relative to what is expected, is recognized as a core characteristic of effective instructional and intervention activities from an SRL perspective. However, research has also shown that teachers often do not provide sufficient regulatory and process feedback to help students re-strategize or adjust their approaches to learning (Cleary and Zimmerman 2006; Hattie and Timperley 2007). Teaching of NOS using an explicit and reflective approach is not enough; monitoring students' self-regulated learning processes while learning is an important additional piece to this puzzle.

To illustrate the nature of this feedback loop and how SRL processes are connected to learning NOS in a classroom context, which further demonstrates the usefulness of monitoring self-regulated learning processes in students while enacting an explicit and reflective NOS approach, consider the following case scenario of a student who poorly integrates SRL processes in his learning. Andrew, a student of average intellectual potential, displays very poor integrated thinking skills and regulation

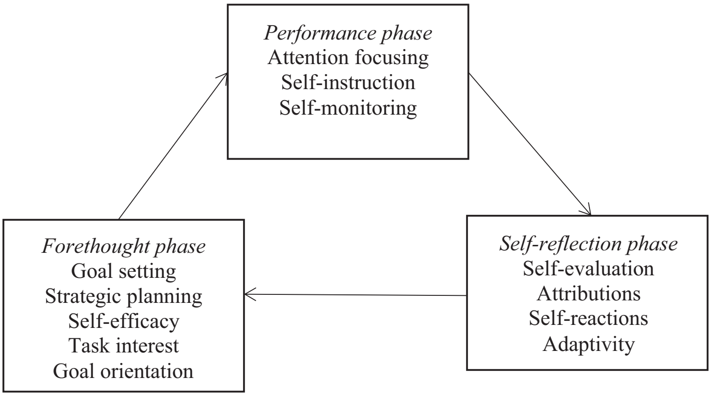


Fig. 6.1 Subprocesses of self-regulated learning

Table 6.1 Definitions of sub-processes of self-regulated learning

Subprocess	Definition
Forethought	
Goal setting	Decisions made about the focus of learning (Locke and Latham 1990)
Strategic planning	Methods chosen by learner to attain goals (Zimmerman and Martinez-Pons 1992)
Self-efficacy	Personal beliefs about one's ability to perform a task (Bandura 1986)
Task interest	Orientation to continue learning, even if there are no rewards (Deci 1975)
Goal orientation	Continuum ranging from wanting to look successful, even if there is no deep learning, to mastery of the task, even if there are no rewards (Ames 1992)
Performance	
Attention focusing	Ability for a learner to shift focus away from distractions and attend to the most profitable information (Corno 1993)
Self-instruction	Ability for learner to continue to proceed through a learning task (Schunk 1982)
Self-monitoring (metacognitive monitoring)	Ability for learners to be aware of their learning processes and check on the forward movement of these processes (Flavell 1979)
Self-reflection	
Self-evaluation	Examining the result of a performance and considering points of alignment and misalignment with an exemplary case (Zimmerman 2000)
Attributions	Ascribing the reasons why alignment or misalignment occurred during the performance (Zimmerman and Martinez-Pons 1992)
Self-reactions	The ways learners feel and behave in a positive or negative way once they self-evaluate (Zimmerman and Kitsantas 1997)
Adaptivity	Ability to change a learning strategy or to seek help effectively if there is a failure or misalignment with exemplar (Zimmerman and Martinez-Pons 1992)

of his behaviors during projects. Upon hearing from his teacher that the class was going to conduct a design project for a model small animal habitat at the local zoo, Andrew became nervous because he realized that he had performed poorly on his last few projects. To try and motivate himself, Andrew states very broadly, “This time I am really going to focus.” Although many of his classmates proactively made a specific plan for the assignment (*strategic planning*), such as identifying the types of tasks involved and chunking them into smaller objectives, Andrew approached the assignment in a very general and non-strategic manner. For example, to complete the assignment of researching key phenomena about the needs of the animals for the habitat and choosing appropriate variables to measure in the design, Andrew read over his notes from his STEM class and looked at a couple of old homework assignments from the unit on engineering design process (*learning strategy*). Andrew found two types of variables that he believed contributed to areas of optimization in the design, and said “this is good enough I guess.” During the project design, Andrew spent 30 min trying to measure these variables and believed he was on the right track (*metacognitive or self-monitoring*) but became discouraged after his teacher told him that he was measuring variables that were not relevant. Instead of asking his teacher for further clarification (*help seeking*), he returned to his typical pattern of waiting to see what his classmates were doing and then copying them.

In short, Andrew did not engage in further reflective thinking and appeared to give up because he lacked the confidence to continue (*self-efficacy*) and believed that he just was not good at science (*attributions*). Upon receiving a 62% on the project report, Andrew rolled his eyes and shoved the report in his binder. He fleetingly thought to himself that he just can’t do STEM and lamented about how “dumb” and ineffective his teacher was as an instructor (*attribution*s).

On the other hand, a skilful learner in science, Sabrina, begins by setting a goal for the year that is focused on learning rather than on recognition, “I will learn the role of evidence in science” (*goal setting)* and sets benchmark goals to reach this distant goal, “I will find out why multiple trials are required for compelling evidence.” The type of goal that she sets indicates that Sabrina understands the hierarchy of her set of goals. This process of setting goals has worked for her in other classes, so she believes that this strategy will work for her in her science class this year. She feels ownership of this type of learning because the teacher has explicitly described how scientific epistemologies relate to the content knowledge and to the labs they do in class, so she is intrinsically interested in learning how to think scientifically (*task value)*. She feels comfortable being challenged in her scientific thinking because the teacher supports her synthesis of domains of knowledge by pointing out how different fields of science discover and validate knowledge (*self-efficacy)*. During class, Sabrina often asks why particular processes in science are used, and the teacher elaborates on the scientific enterprise in response (*attention focusing and elaboration)*. She is aware of what she needs to do to solve problems in science because instead of following a prescribed set of steps, Sabrina has developed a way of knowing in science that allows her to compare how professional scientists act and think to her own thinking (*self-monitoring*). She actively seeks out help when her ways of knowing in science don’t correspond to the nature of science (*help seeking*). She doesn’t worry too much about "messing up" during science labs, because she knows that the teacher provides students opportunities to reflect on the logic of their own thinking. When Sabrina fails at a task or assignment, she knows that she needs to try some other learning strategy (*adaptivity)*, and she draws from the explicit instruction the teacher gives her about how the teacher learns to adapt the ways that she is thinking about her scientific inquiry in class (*self-evaluation*). The compilation of successes and failures along with their corresponding learning strategies help Sabrina to make a library of academic strategies that work for her and she draws from them to create new goals, with the help of the teacher's instruction (*attribution)*.

Despite the growing level of support in the research community for combining SRL practices and academic instruction (Schraw et al. 2006), there is research showing that teachers tend to lack sufficient knowledge and skills to provide quality SRL-related instruction and feedback (Cleary and Zimmerman 2006; Wehmeyer et al. 2000). Although teachers perceive SRL instruction and interventions to be extremely valuable and important in schools, the large majority of them report being ill-prepared to deliver SRL interventions or to provide feedback that enhances students' SRL thinking and behaviors.[7] Although there are several types of feedback that teachers provide students, such as praise and correct answers to problems, feedback about student processes of learning are the least used (Hattie and Timperley 2007). This is troublesome because SRL feedback tends to help students engage in deeper level processing during learning and provides explicit prompts on how students can improve their regulation of behaviors during the task.[8]

6.11 Parallels Between SRL and Explicit and Reflective NOS Instruction

Mapping the ideas about NOS instruction from the science education literature onto the model for self-regulated learning theory (SRL) illustrates a parallel alignment of processes for both science education and educational psychology. Perhaps more importantly, this mapping also has the potential to reveal processes of learning empirically supported in SRL theory that are missing from the description of explicit and reflective approaches. Using phases of learning in an SRL model to explain explicit and reflective learning processes elaborates student processes of learning and motivation that could occur in NOS instruction and provides devices from which to plan curriculum, develop models for mentoring, and monitor each factor of a learner's process during NOS instruction.

[7] Cleary (2009), Cleary and Zimmerman (2006), Coalition for Psychology in Schools and Education (2006), Grigal et al. (2003), Wehmeyer et al. (2000).

[8] Earley et al. (1990), Muis (2004), Shute (2008), Wood and Bandura (1989).

Table 6.2 Forethought phase subprocesses aligned to current explicit NOS instruction literature

Forethought phase subprocess	Explicit NOS instruction
Goal setting	"Cognitive instructional outcomes that should be intentionally targeted" (Khishfe and Abd-El-Khalick 2002, p. 555)
	"should be planned for instead of being anticipated as a side effect or secondary product" (Akindehin 1988, p. 73)
	"Embedded in the context of learning science content" and "highlight the target aspects of NOS" (Akerson et al. 2000, p. 297 and p. 300)
Strategic planning	Learning declarative knowledge about each NOS aspect, then application of each NOS aspect, then integration of NOS aspects with a way of knowing in science through context of content (Akerson and Volrich 2006; Bell et al. 2011; Matthews 2014; McDonald 2010)

6.11.1 Parallels Between Explicit NOS Instruction and SRL Theory

Science teacher educators and researchers have found explicit approaches effective in teaching NOS, such as intentionally planning for NOS instruction within a lesson and creating teachable moments to point out how students are acting and thinking like scientists. The means to which explicit NOS instruction has been used in science education literature have similarities to the forethought phase, specifically in the goal setting and strategic planning processes (Table 6.2 and Fig. 6.2).

6.11.1.1 Goal Setting and Strategic Planning

Goal setting refers to the decisions made regarding specific outcomes of learning and determines the point at which self-reflection occurs at the end of one cycle. More plainly stated, goal setting tells a learner when they have reached their chosen end point of learning. A productive self-regulated learner is able to set goals that are achievable and are steps toward long term goals (Locke and Latham 1990). Once advantageous goals are established, a learner then strategically plans how to achieve the goals. However, in science, a student may be unable to articulate goals because of her inexperience with the subject or lack of contact with scientists (Hogan 2000). Therefore, explicit teaching of NOS by a teacher helps a student set goals by having an expert point out instances when she engages in scientific thinking and helps strategic planning toward the goals. The recommendation of explicit instructional techniques by the science education community can be seen as parallel to goal setting because the process of explicit NOS teaching deliberately targets instructional outcomes involving NOS.[9] Teaching by using the current explicit NOS approaches

[9] Akerson et al. (2000), Akerson and Volrich (2006), Akindehin (1988), Khishfe (2008, 2014), Khishfe and Abd-El-Khalick (2002).

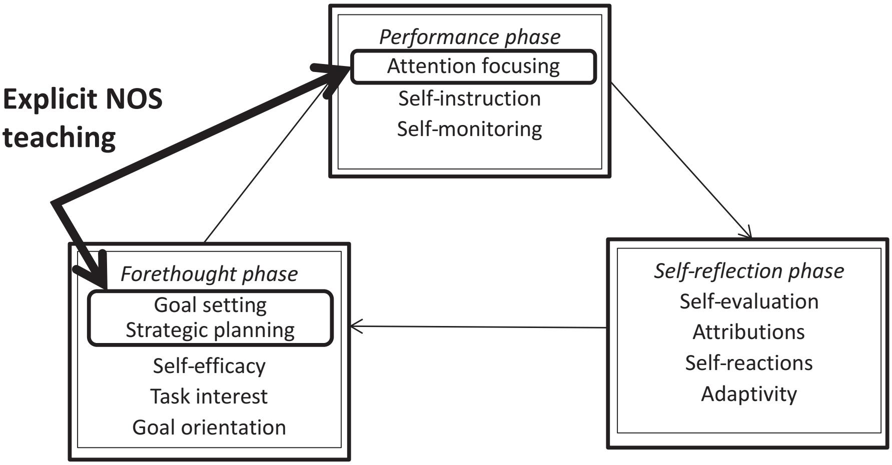


Fig. 6.2 Subprocesses of self-regulated learning theory that are addressed with current explicit NOS instruction

involves modeling goal setting for students until they can become experienced enough to set their own goals and plan strategically how to reach them. For students who may feel that passing the course is their only goal, teachers can talk to students about the value of understanding ways of knowing in science for the purposes of making rationale decision in the civic domain. Teachers can support students to be independent scientific thinkers by modeling forethought phase processes through explicit teaching of NOS. Later, when a student becomes more aware of how to set goals, she can do this goal setting on her own. For example, once a student learns that scientists are dependent on empirical evidence to develop scientific knowledge, she can then set goals to learn how scientists use empirical evidence in different contexts. This shifting responsibility for setting learning goals about NOS knowledge is necessary for a student to become an independent learner. Unfortunately the student learning process is not articulated well in the current NOS literature. The theory of SRL can give guidance for the shift from teacher modeling goal setting to student goal setting and strategic planning. Further examination of NOS instruction as compared to the SRL model demonstrates that there are also non-cognitive factors of learning that the science education community has not yet considered such as self-efficacy, task value and goal orientation.

6.11.1.2 SRL Forethought Subprocesses Not Addressed in Explicit NOS Instruction

Teachers can directly influence goal setting and strategic planning processes by deliberately planning for and pointing out aspects of NOS in science learning for students, and then fading this support so that students take on responsibility for learning (Peters and Kitsantas 2010a). However, effective learning during the forethought phase is influenced by more than just goal setting and strategic planning (Zimmerman 2000). Learning in the forethought phase involves non-cognitive factors such as self-efficacy, task interest, and goal orientation (see Fig. 6.4 for processes not currently addressed by explicit and reflective NOS approaches). Although teachers have less influence on the non-cognitive factors of learning because they come internally from the learner, teachers can design learning environments that can support student's non-cognitive processes in NOS instruction. Self-efficacy of learning about NOS is key because it is the driver for perseverance and changes in behavior and there are four sources from which people acquire their self-efficacy: past performance, observing others perform, verbal persuasion, and one's own physiological cues such as excitement or anxiety (Bandura 1986). One's own judgement of their self-efficacy is heavily determined by their prior experiences with the topic. If a student does not believe she can learn about NOS, then she is unlikely to try to uncover the ways scientists perform in their discipline while she is learning. When a learner believes she can be successful, confidence in their ability to learn science increases and she seeks more challenging tasks in the field.

Teachers can increase self-efficacy of NOS views in students by setting up a learning environment where students initially feel successful at learning tasks and then progress to more challenging learning situations. This could be done by first setting up learning situations that engage students with the NOS aspects that have been found to be easier to learn, such as the aspect of empirical evidence. A student also establishes her self-efficacy when she sees another learner accomplish a task. Verbal persuasion, such as encouragement, is an influence, but has less effect when it is general and not linked to student behavior. Empty praise does little or nothing to enhance self-efficacy of students. Physiological cues, such as sweaty palms or a dry mouth, may indicate impending failure to a student embarking on a learning task. These cues are the weakest of the sources of self-efficacy, but nonetheless, having a relaxing and supportive learning environment in science class can reduce the ill effects of physiological cueing.

A learner who has more interest in a task tends to be more emotionally invested and will have more perseverance than a learner who has less interest in the learning task. To clarify, task interest is not judged by the level of fun the participant is having, rather it is thought of as the learner's perspective of the utility and importance of the learning (Garcia and Pintrich 1994). There is potential in improving NOS learning outcomes in students by addressing task interest of students in classrooms, according to SRL learning theory. Students' interests in learning about NOS can be enhanced by providing an opportunity for students to learn why it is important to regard the aspects of NOS and how the scientific discipline operates. For example, take the case of a student learning about the ideal gas law by memorizing the formula versus another student understanding historical perspectives of how ideas have developed and converged over time. Typically, the student experiencing the latter would value the task more and find it more relevant (Allchin 2011). Invested learners are committed to their goals, exert greater efforts in reaching the goals and demonstrate persistence in their learning (Zimmerman 2000). In opposition, reactive learners take little responsibility for their own learning and rely on outside indicators or extrinsic rewards to determine success. Addressing the level of student interest in the task of learning about NOS is a necessary component of effective learning approaches.

Goal orientation is a variable in SRL that ranges from mastery goal orientation to performance goal orientation. Students who possess a mastery goal orientation develop competencies and face their deficiencies as learning opportunities. A student is a better learner when she seeks to improve intellectually, rather than seeks to gain recognition relative to others such as in a performance goal orientation. Mastery goal orientation is positively correlated with a preference for challenging activities high levels of interest, task involvement, and persistence (Ames and Archer 1988; Elliot and Dweck 1988). Performance goal orientation is correlated positively with surface level learning strategies and self-handicapping strategies such as "I'm just not good at science anyway" (Graham and Golan 1991). Being aware of how a student is oriented in terms of goals and why she is oriented in that way can help a teacher reveal to the student why she may be reticent to learn and help her become better at learning how to learn, particularly learning how science works as a discipline. From this point of awareness, teachers can support students to gradually move themselves from performance orientation to mastery orientation, eventually resulting in deeper learning about science and deeper learning of science.

6.11.2 Performance Phase Subprocesses

An important feature of using a learning theory perspective to analyze curriculum and instruction is the potential to reveal the portions of the learning activities that do not address the requirements in the learning theory. The analysis of current information on NOS instruction through SRL learning theory illustrates that only one of the three processes involved in the performance phase of learning, attention focusing, is addressed by current NOS approaches (Table 6.3). Many researchers suggest that in explicit NOS approaches that learner attention is focused on various aspects of NOS throughout the lessons.[10] This does address one of the processes in the performance phase, but does so from the teacher's perspective, not from the learner's perspective.

Table 6.3 Performance phase subprocesses aligned to current explicit NOS instruction literature

Performance phase subprocesses	Explicit NOS instruction
Attention focusing	Focuses learner attention on various aspects of NOS (Akerson and Volrich 2006; Bell et al. 2011; Khishfe 2008, 2012; Matthews 2014; McDonald 2010)

[10]Akerson and Volrich (2006), Bell et al. (2011), Khishfe (2012), Matthews (2014), McDonald (2010).

The recommendation to focus learner attention on various aspects of NOS can be elaborated by incorporating ways for a learner to become aware of the features she is focusing on during learning. Since a student may initially need support, a teacher can follow the recommendations in the current literature, with the understanding that eventually a learner must take responsibility for being aware of her own attention focusing.

6.11.2.1 SRL Performance Phase Subprocesses Not Addressed in Explicit NOS Instruction

The subprocesses of the performance phase of SLR learning theory not addressed in current recommendations for explicit and reflective NOS instruction include self-instruction and self-monitoring (see Fig. 6.4). Self-instruction refers to the ability of a learner to tell herself how to proceed in a learning task (Schunk 1982). For example, a person who is first learning how to drive a car will either verbally or mentally create a checklist to help her attend to all of the important steps such as adjusting rear view mirrors, placing the car in drive, and applying the brake appropriately. As the learner becomes a more experienced driver, she automatizes this list and no longer needs to self-instruct at such a level of detail. In science, a novice learner may be unaware of what steps to take to help her determine what criteria are used to create knowledge that is scientifically valid. Again, teachers can structure learning environments to include supports such as checklists for students to explicitly understand NOS ideas when they are engaging in scientific endeavors (Peters and Kistantas 2010a; Peters-Burton 2012), with an attention towards fading the support when the student is ready to self-instruct on her own.

Self-monitoring or metacognitive monitoring is a very important component in this learning cycle because it can be the difference between active and passive learning (Cleary and Platten 2013; Peters 2012), and seems to be lacking in current NOS learning approaches. Self-monitoring requires one to be able to choose a standard or a goal to which one can realistically compare their performance. Components of the SRL cycle are interrelated, because the goal setting done in the forethought phase greatly influences the success of the metacognitive monitoring process (Peters and Kitsantas 2010b). Selecting a relevant and attainable goal affects the ability to compare one's performance with the goal. For example, if a learner sets a poor goal such as "I want to learn how scientists think," it is difficult to monitor one's own success in reaching that goal because it is too vague. Instead, if a learner sets an advantageous goal such as "I will analyze the connections between the evidence and the claim made in an investigation," then the learner has a clearer standard from which to judge the success of their performance in the learning task. Although current explicit NOS approaches do not address these processes, it is possible to influence self-instruction and self-monitoring in a positive way in the future by using a SRL model adapted for NOS instruction.

6.11.3 Parallels Between Reflective NOS Instruction and SRL Theory

Similar to the explicit NOS approaches and their alignment to some of the subprocesses in the forethought and performance phases, reflective NOS instruction seems to corresponds directly to the self-reflection phase of SRL theory (Fig. 6.3), as the names might suggest. The subprocesses in the self-reflection phase of the SRL cycle that have similarities to the description of NOS approaches include self-evaluation and adaptivity (Fig. 6.3). For a third time, the SRL theory model has a potential to illuminate additional factors involved in learning that are not addressed in the science education literature recommendations, specifically self-reactions and attributions.

6.11.3.1 Self-Evaluation and Adaptivity

Based on all of the processes in the self-reflection phase, the current reflective NOS approaches from the literature are most aligned with the subprocess of self-evaluation (Table 6.4). Khishfe and Abd-El-Khalick (2002) recommended "providing students with opportunities to analyze the activities in which they are engaged… to map connections between their activities and ones undertaken by others (e.g., scientists) and to draw generalizations" (p. 555). The subprocess of self-evaluation requires one to compare the outcomes of the performance with a standard or exemplar performance from a well-respected source (Zimmerman 2000). In this case, the

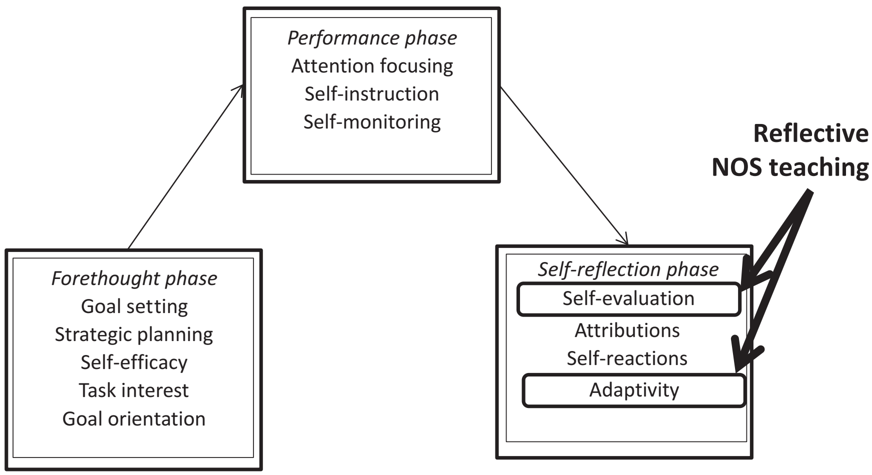


Fig. 6.3 Subprocesses of self-regulated learning theory that are addressed with current explicit and reflective NOS instruction

Table 6.4 Self-reflection phase subprocesses aligned to current reflective NOS instruction literature

Self-reflection subprocess	Reflective NOS instruction
Self-evaluation	"Providing students with opportunities to analyze the activities in which they are engaged from various perspectives (e.g., a NOS framework), to map connections between their activities and ones undertaken by others (e.g., scientists), and to draw generalizations about a domain of knowledge (e.g., epistemology of science)" (Khishfe and Abd-el-Khalick 2002, p. 555).
	Reflective instruction should challenge learners to think about how their work illustrates NOS, and how their inquiries are similar to or different from the work of scientists (Scharmann et al. 2005)
Adaptivity	"Reflective elements are designed to emulate the sort of activities that historians, philosophers, and sociologists engage in their efforts to understand the workings of science" (Abd-El-Khalick and Lederman 2000, p. 691)

recommendation is for the student to reflect on how well they acted as compared to how a scientist would act and then make a generalization about this work. The current literature on NOS approaches fully aligns with the SRL theory for the subprocess of self-evaluation, as long as there are ways that a student is able to evaluate her own performance without teacher support in future attempts.

Adaptivity refers to the ability of a learner to be able to change course in learning if needed. The more experience a learner has, the more adaptable her reactions to self-evaluations become. Abd-El-Khalick and Lederman (2000) suggested that "reflective elements are designed to emulate the sort of activities that historians, philosophers, and sociologists engage in their efforts to understand the workings of science" (p. 691). This example encourages adaptivity because it draws from three different disciplines from which to judge one's own understanding of NOS. In this process, a learner tries a variety of learning strategies and perspectives until she find the ones that are most successful for her in the situation. Having many disciplines from which to understand NOS is beneficial to adaptivity in a learner.

Knowledge of NOS allows a student to think more flexibly about *why* they undertake the processes they do in scientific inquiry and how she can adapt her process if an error occurs. Reflecting on the aspects of NOS when considering findings of an inquiry activity, a learner has information to draw from regarding the validity of scientific work. A learner's accurate judgment of her self-evaluation helps her to attribute successes and failures in the performance to appropriate sources, causing a positive self-reaction which will help her be more productive. If a student attributes her successes and failures to appropriate sources, she can be an adaptive learner and continue to learn more material efficiently. Multiple cycles through the SRL model reinforce the learner to be more strategic the next time she is attending to a learning task (Zimmerman 2000).

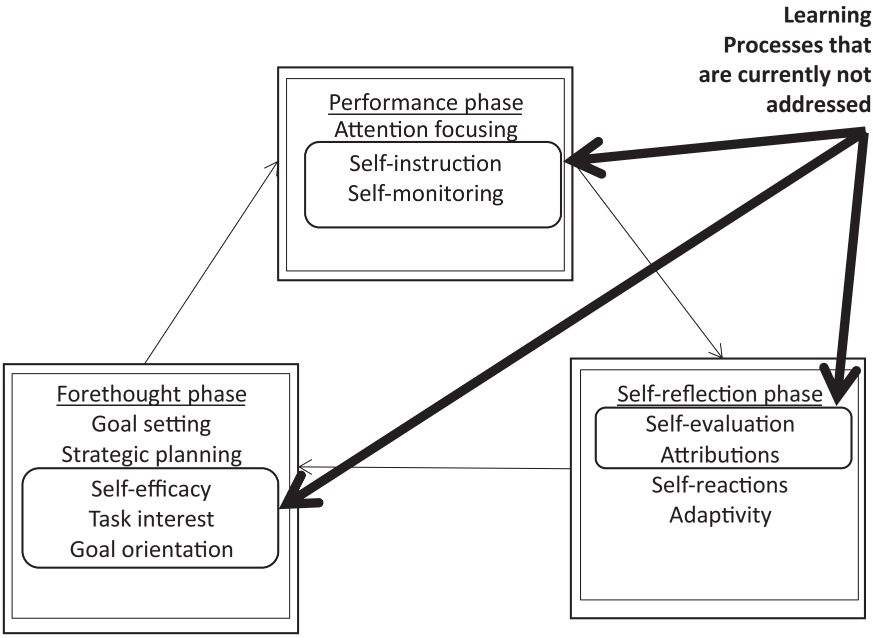


Fig. 6.4 Subprocesses that are not currently addressed by explicit and reflective NOS approaches

6.11.3.2 SRL Performance Phase Subprocesses Not Addressed in Explicit NOS Instruction

Self-reactions and attributions appear to be lacking in recommendations for reflective NOS instruction (see Fig. 6.4). After the performance of a task, a learner often engages in self-evaluation first and compares self-monitored information against a standard or goal. Here the standard or goal is the activity of scientists, and in this phase of learning a teacher is in effect asking a student to self-evaluate her performance in science against the standard of the discipline. Once a learner self-evaluates her performance and judges it to be aligned or misaligned with a standard, she ascribes attributions to her successes or failures. If a student is not aware of the standard which she should compare against, she will never know if she is doing well or not in their learning.

Attributing success or failure to a performance is key in promoting learning because if the learner attributes errors to their ability (she was not born with the skills of being a scientist) or an outside factor (the belief that the student made errors because the teacher just doesn't like her) rather than effort or process, then the learner may give up trying to improve (Graham and Williams 2009). That is, a productive learner attributes her successes or failures in a task to strategies, effort, and perseverance. Given the chance to reflect on her understanding of science, a student has the opportunity to see her strategies retroactively and could be encouraged to attribute her successes or errors to effort rather than innate ability, which results in a more effective learner.

Additionally, a student who has an understanding of science can comprehend that there is a rationale for the strategies utilized in science, rather than harbor an understanding that a person's ability to think like a scientist is innately granted. Positive attribution leads to positive self-reactions, which are the methods a person chooses to further their understanding of the learning situation or the way they react to their self-evaluation and attribution. A learner who reacts to the evaluation of their performance by saying "the teacher just doesn't like me" or "I'm just not naturally good at science" will do little to improve the ways she approaches learning. A learner who reacts by saying, "wow, I just did not study well for this test" or "I should have asked the teacher about the things I didn't understand when I had the chance" has reacted in a positive way and will most likely learn from her mistakes. Consider the situation when a student conducting scientific inquiry in the classroom with a group and the data analysis she is carrying out does not yield a consistent trend. The learner could give up and resign herself to not being science-minded (a negative attribution and self-reaction) or the learner could reconsider her strategies and reflect upon what is "scientific" and realize that more trials are needed for a valid and reliable investigation of the scientific phenomena.

6.12 Categories of NOS That Are Supported by SRL Theory-Based Curriculum

Although SRL theory phases appears to align with current calls for explicit and reflective NOS instructional approaches, and is a tool to reveal some of the learning processes that should be addressed in the future, SRL theory is less helpful for some aspects of NOS knowledge. The aspects of NOS overlap and are not mutually exclusive, but examining the types of knowledge that make up NOS can help identify the ones that are most fruitfully situated in SRL theory. Irzik and Nola (2014) present eight categories of science organized into two domains, science as a cognitive-epistemic system and science as a social system in their framework. The categories in the cognitive-epistemic system are processes of inquiry, aims and values, methods and methodological rules, and scientific knowledge. The categories in the social system of NOS in Irzik and Nola's framework include professional actions, scientific ethos, social certification, and social values. Within this framework some categories of NOS are more performance based and some are more situated in underpinnings of science, which are more difficult to form into a learning task for self-regulated learning processes. The categories of NOS that work well in the SRL approach include almost all of the categories: processes of inquiry, aims and values, methods and methodological rules, scientific knowledge, professional actions, scientific ethos, and social certification. These aspects are useful in setting up and carrying out investigations and because they are performance based, they are easier content from which to set goals, monitor goals and evaluate the success of reaching these goals.

For example, scientists must use creativity in developing questions, choosing measurement techniques, and interpreting results. Scientists also must employ habits of mind such as organization and skepticism in order to obtain empirical results and collaborate to figure out how to be as rigorous as possible. In turn, the use of empirical results can lead to valid claims. Claims made by scientists are peer reviewed by other scientists who employ the same habits of mind to check transparency of the empirical evidence and the validity of the claims connected to the evidence. Students can evaluate scientific endeavors for alignment with the aims and values of science. All of these activities can occur on a personal level and contribute to the practice of science among the community of scientists.

The one category of NOS that is difficult to fit into the SRL approach is social values. Irzik and Nola (2014) describe social values as "freedom, respect for the environment and social utility broadly understood to refer to improving people's health and quality of life as well as to contributing to economic development" (p. 1008). This category of NOS seems to be a broader view of the body of knowledge known as science and the ways this body of knowledge is constructed. Because this is difficult to demonstrate either cognitively or through performance, it is difficult to form into a learning task related to the SRL cycle. This level of NOS aspects describes a background of ideas about the nature of knowledge and knowing, rather than observable practices of science. The social values of this NOS framework may be more difficult to assess using the SRL phase models subprocesses because it is an underpinning, rather than an overt activity.

6.13 Results of Using SRL of NOS in the Classroom

Some evidence from quasi-experimental studies has shown that the use of SRL theory is related to improved outcomes for learning NOS. A series of studies involving almost 300 eighth- graders participating in an 8-week intervention that supported their self-regulated learning of NOS while engaged in guided inquiry on electricity and magnetism showed promising results. The intervention consisted of a four-phase coaching strategy: (a) the teacher modeled the example of NOS in the context of the investigation, for example explaining the key characteristics of scientific observations about magnets, (b) the students used a checklist listing NOS aspects expected to be present in their work when performing an independent investigation, such as the need for replicability, (c) the students were encouraged to continue engaging with NOS independently while using a shorter checklist, and (d) students answered questions about their rationale for the NOS aspects present in their investigations. The experimental group was given the prompts, while the comparison group performed the inquiry without the checklists and studied from their textbooks so that there was equal time on task between the groups. The students who participated in the intervention outperformed the comparison group in the areas of NOS knowledge and in subject matter knowledge (Peters and Kitsantas 2010b; Peters 2012). That is, even the students who engaged with the content for a longer period of time learned less content than the students engaged with NOS using the SRL coaching technique.

In another investigation of student learning in NOS using a SRL approach, seventh- and eighth-grade students who participated in a cycle of SRL-based instruction of NOS demonstrated an increased number of connections among ideas about empirical evidence, habits of mind, and tentativeness (Peters-Burton 2015b). In this investigation, SRL subprocesses were deliberately built into the curriculum of a NOS class for the students. Evidence from measures collected from pre- and post-epistemic network analysis show direct connections between the NOS aspects taught using SRL subprocesses and shifts in the idea nodes on the maps. Student learning outcomes included broader understanding of scientific endeavors beyond experimentation and a shift toward an understanding that knowledge is tentative.

SRL theory has also been helpful in teaching in-service teachers about NOS aspects and inquiry-based teaching. A temporally-based technique called SRL microanalysis was useful in informing instructional strategies during professional development experiences. (Peters-Burton 2013, 2015a). SRL microanalysis is a context-specific structured interview protocol that directly examines individuals' cyclical-phase SRL processes as they engage in authentic learning activities and are designed to capture individuals' phase-specific SRL processes (i.e., forethought, performance, and self-reflection) during task engagement (Cleary 2011; Cleary et al. 2012). SRL microanalysis revealed that teachers' goal setting and self-monitoring processes were unproductive early in the programme. Consequently, the professional development programme was adapted to support teachers to create process goals to reach their objective to teach earth science through inquiry (Peters-Burton 2013). Similarly, SRL microanalysis was used to enhance the learning processes of secondary in-service teachers who were learning how to teach argumentation (Peters-Burton 2015a). The adaptation of the instruction during the professional development was facilitated by interviewing learners about SRL subprocesses while they were learning and adapting the learning environment to support the weakest subprocesses.

6.14 Conclusion

Finding ways to effectively teach NOS has been a focus for many years in science education. Current methods of explicit and reflective NOS instruction have been somewhat successful but have mainly focused on teacher behavior in the classroom, rather than how students learn NOS. SRL theory provides one way to examine how a student learns. Mapping current approaches of teaching NOS onto SRL learning processes shows that there are some learning processes addressed by explicit and reflective methods but other learning processes that are ignored. SRL theory provides two opportunities to improve NOS instruction: (a) use as a framework to consider processes of student learning when designing curriculum and (b) use as a tool to inform teachers of learning processes that are skillfully used by a student and those that are not.

Adopting SRL models of learning for NOS instruction can further inform factors of learning and motivation, leading to more successful curriculum design than is currently available with explicit and reflective NOS approach recommendations. Further, Erduran and Dagher (2014) propose that the Family Resemblance Approach will spark more student interest and motivation than prior approaches, and SRL models have the capacity to monitor student motivation. More precision is needed about why explicit and reflective methods are effective and the SRL model provides empirically-derived variables of learning that haven't yet been considered in science education. SRL theory as applied to NOS instruction helps to expand and explain many of the processes of learning that occur by the use of explicit and reflective methods and those that are not yet established in science education.

References

Abd-El-Khalick, F. (2005). Developing deeper understandings of nature of science: The impact of a philosophy of science course on preservice science teachers' views and instructional planning. *International Journal of Science Education, 27*, 15–42.

Abd-El-Khalick, F., & Lederman, N. G. (2000). Improving science teachers' conceptions of the nature of science: A critical review of the literature. *International Journal of Science Education, 22*, 665–701.

Abd-El-Khalick, F. S., & Akerson, V. L. (2004). Learning about nature of science as conceptual change: Factors that mediate the development of preservice elementary teachers' views of nature of science. *Science Education, 88*, 785–810.

Abd-El-Khalick, F., Bell, R. L., & Lederman, N. G. (1998). The nature of science and instructional practice: Making the unnatural natural. *Science Education, 82*, 417–436.

Akerson, V. L., & Hanuscin, D. L. (2007). Teaching nature of science through inquiry: Results of a 3-year professional development program. *Journal of Research on Science Teaching, 44*, 653–680.

Akerson, V. L., & Volrich, M. L. (2006). Teaching nature of science explicitly in a first grade internship setting. *Journal of Research in Science Teaching, 43*, 377–394.

Akerson, V. L., Abd-El-Khalick, F., & Lederman, N. G. (2000). Influence of a reflective explicit activity-based approach on elementary teachers' conceptions of nature of science. *Journal of Research in Science Teaching, 37*, 295–317.

Akindehin, F. (1988). Effect of an instructional package on preservice science teachers' understanding of the nature of science and acquisition of science-related attitudes. *Science Education, 72*, 73–82.

Allchin, D. (2011). Evaluating knowledge of the nature of (whole) science. *Science Education, 95*, 518–542.

Alters, B. J. (1997). Whose nature of science? *Journal of Research in Science Teaching, 34*, 39–55.

Ames, C. (1992). Achievement goals and the classroom motivational climate. In D. H. Schunk & J. L. Meece (Eds.), *Student perceptions in the classroom* (pp. 327–348). Hillsdale: Erlbaum.

Ames, C., & Archer, J. (1988). Achievement goals in the classroom: Students' learning strategies and motivational processes. *Journal of Educational Psychology, 80*, 260–267.

Bandura, A. (1986). *Social foundations of thought and action: A social cognitive theory*. Englewood Cliffs: Prentice-Hall.

Bandura, A. (2001). Social cognitive theory: An agentic perspective. *Annual Review of Psychology, 52*, 1–29.
Bell, R. L., Matkins, J. J., & Gansneder, B. M. (2011). Impacts of contextual and explicit instruction on preservice elementary teachers' understandings of the nature of science. *Journal of Research in Science Teaching, 48*, 414–436.
Billeh, V. Y., & Hasan, O. E. (1975). Factors influencing teachers' gain in understanding the nature of science. *Journal of Research in Science Teaching, 12*, 209–219.
Chinn, C. A., & Malhotra, B. A. (2002). Epistemologically authentic inquiry in schools: A theoretical framework for evaluating inquiry tasks. *Science Education, 86*, 175–218.
Cleary, T. J. (2009). School-based motivation and self-regulation assessments: An examination of school psychologist beliefs and practices. *Journal of Applied School Psychology, 25*, 71–94.
Cleary, T. J. (2011). Shifting towards self-regulation microanalytic assessment: Historical overview, essential features, and implications for research and practice. In B. J. Zimmerman & D. H. Schunk (Eds.), *Handbook of self-regulation of learning and performance* (pp. 329–345). Abingdon: Routledge.
Cleary, T. J., & Labuhn, A. S. (2013). Application of cyclical self-regulation interventions in science-based contexts. In H. Bembenutty, T. J. Cleary, & A. Kitasantas (Eds.), *Applications of self-regulated learning across diverse disciplines: A tribute to Barry J. Zimmerman* (pp. 89–124). Charlotte: Information Age Publishing.
Cleary, T. J., & Platten, P. (2013). Examining the correspondence between self-regulated learning and academic achievement: A case study analysis [Special issue]. *Educational Research International.*
Cleary, T. J., & Zimmerman, B. J. (2006). Teachers' perceived usefulness of strategy microanalyic assessment information. *Psychology in the Schools, 43*, 149–155.
Cleary, T. J., Callan, G., & Zimmerman, B. J. (2012). Assessing self-regulation as a cyclical, context-specific phenomenon: Overview and analysis of SRL microanalytic protocols [Special issue]. *Education Research International*.
Clough, M.P. (2007). Teaching the nature of science to secondary and post-secondary students: Questions rather than tenets, The Pantaneto forum, issue 25, January, http://www.pantaneto.co.uk/issue25/front25.htm. Republished (2008) in *California Journal of Science Education, 8*(2), 31–40.
Coalition for Psychology in Schools and Education. (2006). *Report on the teacher needs survey*. Washington, DC: American Psychological Association, Center for Psychology in Schools and Education.
Corno, L. (1993). The best-laid plans: Modern conceptions of volition and educational research. *Educational Researcher, 22*(2), 14–22.
Deci, E. L. (1975). *Intrinsic motivation*. New York: Plenum Press.
Driver, R., Leach, J., Millar, R., & Scott, P. (1996). *Young people's images of science*. Philadelphia: Open University Press.
Dunbar, K. (1993). Concept discovery in a scientific domain. *Cognitive Science, 17*, 397–434.
Duschl, R. A., & Grandy, R. (2012, Online first). Two views about explicitly teaching nature of science. *Science & Education.* DOI 10.1007/s11191-012-9539-4
Earley, P. C., Northcraft, G. B., Lee, C., & Lituchy, T. R. (1990). Impact of process and outcome feedback on the relation of goal setting to task performance. *Academy of Management Journal, 33*, 87–105.
Elliot, E., & Dweck, C. (1988). Goals: An approach to motivation and achievement. *Journal of Personality and Social Psychology, 54*, 5–12.
Erduran, S., & Dagher, Z. R. (2014). *Reconceptualizing the nature of science for science education*. Dordrecht: Springer.
Flavell, J. H. (1979). Metacognition and cognitive monitoring: A new area of cognitive-developmental inquiry. *American Psychologist, 34*, 906–911.
Garcia, T., & Pintrich, P. R. (1994). Regulating motivation and cognition in the classroom: The role of self-schemas and self-regulatory strategies. In D. H. Schunk & B. J. Zimmerman (Eds.),

Self-regulation of learning and performance: Issues and educational application (pp. 127–153). Hillsdale: Erlbaum.

Graham, S., & Golan, S. (1991). Motivational influences on cognition: Task involvement, ego involvement, and depth of processing. *Journal of Educational Psychology, 83*, 187–194.

Graham, S., & Williams, C. (2009). An attributional approach to motivation in school. In K. Wentzel & A. Wigfield (Eds.), *Handbook of motivation at school* (pp. 11–34). New York: Routledge.

Grigal, M., Neubart, D. A., Moon, S. M., & Graham, S. (2003). Self-determination for students with disabilities: Views of parents and teachers. *Exceptional Children, 70*, 97–112.

Hanuscin, D., Akerson, V., & Phillipson-Mower, T. (2006). Integrating nature of science instruction into a physical science content course for preservice elementary teachers: NOS views of teaching assistants. *Science Education, 90*, 912–935.

Hattie, J., & Timperley, H. (2007). The power of feedback. *Review of Educational Research, 77*, 81–112.

Henderson, R. W. (1986). Self-regulated learning: Implications for the design of instructional media. *Contemporary Educational Psychology, 11*, 405–427.

Hodson, D. (1993). Philosophic stance of secondary school science teachers, curriculum experiences, and children's understanding of science: Some preliminary findings. *Interchange, 24*(1&2), 41–52.

Hodson, D. (2014). Nature of science in the science curriculum: Origin, development and shifting emphases. In M. R. Matthews (Ed.), *International handbook of research in history, philosophy and science teaching* (pp. 911–970). Dordrecht: Springer.

Hofer, B. K., & Pintrich, P. R. (Eds.). (2002). *Personal epistemology: The psychology of beliefs about knowledge and knowing*. Mahwah: Erlbaum.

Hogan, K. (2000). Exploring a process view of students' knowledge about the nature of science. *Science Education, 84*, 51–70.

Irzik, G., & Nola, R. (2014). New directions in nature of science research. In M. R. Matthews (Ed.), *International handbook of research in history, philosophy, and science teaching* (pp. 999–1021). Dordrecht: Springer.

Jungwirth, E. (1970). An evaluation of the attained development of the intellectual skills needed for understanding of the nature of scientific inquiry by BSCS pupils in Israel. *Journal of Research in Science Teaching, 7*, 141–151.

Kalman, C. S. (2009). The need to emphasize epistemology in teaching and research. *Science & Education, 18*, 325–347.

Kalman, C. S., & Aulls, M. (2003). Can an analysis of the contrast between pre-Galilean and Newtonian theoretical frameworks help students develop a scientific mindset? *Science & Education, 12*, 761–772.

Khishfe, R. (2008). The development of seventh graders' views of nature of science. *Journal of Research on Science Teaching, 45*, 470–496.

Khishfe, R. (2012). Relationship between nature of science understandings and argumentation skills: A role for counterargument and contextual factors. *Journal of Research in Science Teaching, 49*, 489–514.

Khishfe, R., & Abd-El-Khalick, F. (2002). Influence of explicit and reflective versus implicit inquiry-oriented instruction on sixth graders' views of nature of science. *Journal of Research in Science Teaching, 39*, 551–578.

King, P., & Kitchener, K. (1994). *Developing reflective judgment: Understanding and promoting intellectual growth and critical thinking in adolescents and adults*. San Francisco: Jossey-Bass.

Knorr-Cetina, K. (1999). *Epistemic cultures: How the sciences make knowledge*. Cambridge, MA: Harvard University Press.

Kuhn, D. (1999). A developmental model of critical thinking. *Educational Researcher, 28*, 16–26.

Lawson, A. E. (1982). The nature of advanced reasoning and science instruction. *Journal of Research in Science Teaching, 19*, 743–760.

Leach, J. T., Hind, A. J., & Ryder, J. (2003). Designing and evaluating short teaching interventions about the epistemology of science in high school classrooms. *Science Education, 87*(6), 831–848.

Lederman, N. G., Bartos, S. A., & Lederman, J. (2014). The development, use, and interpretation of nature of science assessments. In M. R. Matthews (Ed.), *International handbook of research in history, philosophy and science teaching* (pp. 971–997). Dordrecht: Springer.

Locke, E. A., & Latham, G. P. (1990). *A theory of goal setting and task performance*. Englewood Cliffs: Prentice Hall.

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: Concepts and methodologies* (pp. 3–26). Dordrecht: Springer.

Matthews, M. (2014). *Science teaching: The role of history and philosophy of science*. New York: Routledge.

McComas, W. F. (2008). Seeking historical examples to illustrate key aspects of the nature of science. *Science & Education, 17*(2/3), 249–263.

McComas, W. F., & Olson, J. K. (1998). The nature of science in international standards documents. In W. F. McComas (Ed.), *The nature of science in science education: Rationales and strategies* (pp. 41–52). Dordrecht: Kluwer Academic Publishers.

McComas, W. F., Lee, C. K., & Sweeney, S. (2009). The comprehensiveness and completeness of nature of science content in the U.S. *state science standards.* Paper presented at the National Association for Research in Science Teaching International Conference, Garden Grove, CA.

McDonald, C. V. (2010). The influence of explicit nature of science and argumentation instruction on preservice primary teachers' views of nature of science. *Journal of Research in Science Teaching, 47*, 1137–1164.

Meichtry, Y. J. (1992). Influencing student understanding of the nature of science: Data from a case curriculum development. *Journal of Research in Science Teaching, 29*, 389–407.

Monk, M., & Osbourne, J. (1997). Placing the history and philosophy of science on the curriculum: A model for the development of pedagogy. *Science Education, 81*, 405–424.

Morrison, J. A., Raab, F., & Ingram, D. (2009). Factors influencing elementary and secondary teachers' views on the nature of science. *Journal of Research on Science Teaching, 46*, 384–403.

Muis, K. R. (2004). Personal epistemology and mathematics: A critical review and synthesis of research. *Review of Educational Research, 74*(3), 317–377.

Ogunnivi, M. B. (1983). Relative effects of a history/philosophy of science course on student teachers' performance on two models of science. *Research in Science & Technological Education, 1*, 193–199.

Osborne, J., Collins, S., Ratcliffe, M., Millar, R., & Duschl, R. (2003). What "ideas-about science" should be taught in school? A Delphi study of the expert community. *Journal of Research in Science Teaching, 40*, 692–720.

Peters, E. E. (2012). Developing content knowledge in students through explicit teaching of the nature of science: Influences of goal setting and self-monitoring. *Science and Education, 21*(6), 881–898.

Peters-Burton, E. E. (2012). Using metacognition to develop understanding of the role of evidence in science. *Science Scope, 35*(9), 14–19.

Peters-Burton, E.E. (2013, April). *Microanalysis of self-regulatory processes of elementary teachers learning to teach earth science through inquiry.* Paper presented at the annual conference of the American education research association, San Francisco, CA.

Peters-Burton, E. E. (2015a, January). *Incorporation of scientific argumentation into instruction: Results from a professional development for high school teachers.* Paper presented at the Annual Meeting of the Association for Science Teacher Education, Portland, OR.

Peters-Burton, E. E. (2015b). Outcomes of a self-regulatory curriculum model: Network analysis of middle school students' views of nature of science. *Science & Education, 24*, 855–885.

Peters, E. E., & Kitsantas, A. (2010a). Self-regulation of student epistemic thinking in science: The role of metacognitive prompts. *Educational Psychology, 30*(1), 27–52.

Peters, E. E., & Kitsantas, A. (2010b). The effect of nature of science metacognitive prompts on science students' content and nature of science knowledge, metacognition, and self-regulatory efficacy. *School Science and Mathematics, 110*, 382–396.

Rudge, D. W., & Howe, E. M. (2009). Sickle cell disease and malaria: An explicit and reflective approach to the use of history to promote understanding of the nature of science. *Science & Education, 18*, 561–580.

Rudolph, J. L. (2002). *Scientists in the classroom: The cold war reconstruction of American science education*. New York: Palgrave.

Sandoval, W. A. (2005). Understanding students' practical epistemologies and their influence on learning through inquiry. *Science Education, 89*(4), 345–372.

Sandoval, W. A., & Morrison, K. (2003). High school students' ideas about theories and theory change after a biological inquiry unit. *Journal of Research in Science Teaching, 40*(4), 369–392.

Scharmann, L. C., Smith, M. U., James, M. C., & Jensen, M. (2005). Explicit reflective nature of science instruction: Evolution, intelligent design, and umbrellaology. *Journal of Science Teacher Education, 16*, 27–41.

Schauble, L., Glaser, R., Duschl, R. A., Schulze, S., & John, J. (1995). Students' understanding of the objectives and procedures of experimentation in the science classroom. *The Journal of the Learning Sciences, 4*(2), 131–166.

Schraw, G., Crippen, K. J., & Hartley, K. (2006). Promoting self-regulation in science education: Metacognition as part of a broader perspective on learning. *Research in Science Education, 36*, 111–139.

Schunk, D. H. (1982). Verbal self-regulation as a facilitator of children's achievement and self-efficacy. *Human Learning, 1*, 265–277.

Schwartz, R. S., Lederman, N. G., & Crawford, B. A. (2004). Developing views of nature of science in an authentic context: An explicit approach to bridging the gap between nature of science and scientific inquiry. *Science Education, 88*, 610–645.

Shute, V. J. (2008). Focus on formative feedback. *Review of Educational Research, 78*, 153–189.

Sinatra, G. M., & Taasoobshirazi, G. (2011). Intentional conceptual change: The self-regulation of science. In B. J. Zimmerman & D. H. Schunk (Eds.), *Handbook of self-regulation of learning and performance* (pp. 203–216). New York: Routledge.

Smith, M. U., & Scharmann, L. C. (2008). A multi-year program developing an explicit reflective pedagogy for teaching pre-service teachers the nature of science by ostention. *Science & Education, 17*, 219–248.

Tamir, P. (1972). Understanding the process of science by students exposed to different science curricula in Israel. *Journal of Research in Science Teaching, 9*, 239–245.

Trent, J. (1965). The attainment of the concept "understanding science" using contrasting physics courses. *Journal of Research in Science Teaching, 3*, 224–229.

Tsai, C. C. (2000). Relationships between student scientific epistemological beliefs and perceptions of constructivist learning environments. *Educational Research, 42*, 193–205.

Wehmeyer, M. L., Agran, M., & Hughes, C. A. (2000). National survey of teachers' promotion of self-determination and student-directed learning. *The Journal of Special Education, 34*, 58–68.

Wong, S. L., & Hodson, D. (2009). From the horse's mouth: What scientists say about scientific investigation and scientific knowledge. *Science Education, 93*, 109–130.

Wood, R., & Bandura, A. (1989). Impact of conceptions of ability on self-regulatory mechanisms and complex decision making. *Journal of Personality and Social Psychology, 56*, 407–415.

Zimmerman, B. J. (2000). Attaining self-regulation: A social-cognitive perspective. In M. Boekaerts, P. Pintrich, & M. Zeidner (Eds.), *Handbook of self-regulation* (pp. 13–39). San Diego: Academic.

Zimmerman, B. J., & Kitsantas, A. (1997). Developmental phases in self-regulation: Shifting from process to outcome goals. *Journal of Educational Psychology, 89*, 1–10.

Zimmerman, B. J., & Kinsantas, A. (2002). Acquiring writing revision and self-regulatory skill through observation and emulation. *Journal of Educational Psychology, 94*, 660–668.

Zimmerman, B. J., & Martinez-Pons, M. (1992). Perceptions of efficacy and strategy use in the self-regulation of learning. In D. H. Schunk & J. Meece (Eds.), *Student perceptions in the classroom: Causes and consequences* (pp. 185–207). Hillsdale: Erlbaum.

Chapter 7
About the Psychological and Logical Moment in Natural Science Teaching (1890)

Ernst Mach

Historical studies convincingly demonstrate that the knowledge process[1] [*Erkenntnis*] in natural science consists of the gradual adaptation of the thoughts to the facts. This adaptation happens through happy circumstances, which increasingly reveal the more general similarities and subtle differences of the facts. By this, the precision of the representation of the facts by the thoughts grows, so that the latter finally become an image of the former, which for certain intellectual purposes may completely substitute for them.

Ernst Mach (translated and edited by Hayo Siemsen).

[1] **Translator's note**: In Mach's understanding, knowledge is a non-teleological process, as part of Lamarck/Spencer/Wallace/Darwin's idea of evolution. Any development, "growth", etc. are local, but not general. Knowledge, like Darwinian species is thus a process generally with a concrete product locally (see also Beneke, 1840, *System der Metaphysik und Religionsphilosophie aus den natürlichen Grundverhältnissen des menschlichen Geistes abgeleitet*. Mach read this text early in his life and applied many ideas from it). Directionality depends on observations relative to a "background", which can never be absolute. The process view was used by Newton in his concept of "interaction" in order to replace the previous "object"/"product" view. The process/gestalt view was also used by Mach in his criticism of Newton's absolute space and time.

Translator's note: The article was first printed in the *Zeitschrift für den physikalischen und chemischen Unterricht*. Berlin: Springer: 1890/1891, 1–5. Über das psychologische und logische Moment im naturwissenschaftlichen Unterricht.
Translated by Hayo Siemsen: Translator's note: For the following references in the footnotes, see Siemsen, H. (2012). Ernst Mach, George Sarton and the Empiry of Teaching Science Part I. *Science & Education*, 21/4: 447–484.
Siemsen, H. (2013). Ernst Mach, George Sarton and the Empiry of Teaching Science Part II. *Science & Education*, 22/5: 951–1000.

E. Mach (deceased)

M.R. Matthews (ed.), *History, Philosophy and Science Teaching*, Science: Philosophy, History and Education, DOI 10.1007/978-3-319-62616-1_7

The one who admits this sober view of the meaning of natural science will assign to natural science teaching[2] no other purpose, but to promote the aspired adaptation of thoughts with highest economy of work on shortcuts, by artificially bringing about those favorable circumstances avoiding the unfavorable historical coincidences and delays.[3] If one has adopted this opinion, it can barely appear strange that, just as an organic being (after Darwin) in its embryonic stage replicates the whole step-ladder of evolutionary development in an abridged way, also in teaching a condensed and clarified imitation of the historical way of development of science has shown to be the most natural and useful; because the next higher level of knowledge has actually established itself, thereby psychologically, on the former lower one, and can in a certain way only be ascended, i.e. fully understood through it.

On different occasions I think I have observed that this stated view is still barely shared in the circles of the teachers. Even those, who theoretically adhere to it, practically defect from it again and again. This mainly, and quite prominently, manifests itself in the overrating of the logical and disregard of the psychological moment in teaching. By stating my opinion on this issue here, I hope – without counting on immediate agreement – to contribute to the discussion and clarification of the pedagogical opinions.

The generally prevalent overrating of the logical moment in relation to the psychological – also when one completely disregards the abnormal outgrowth of it completely[4] – meets us often enough. It probably derives from the time when the

[2] **Translator's note**: Ernst Mach is well known for his influence in physics (spacetime), physiology (psychophysics, the inner ear), psychology (gestalt) or *erkenntnis*-psychology/ theory of knowledge (Erkenntnis und Irrtum). He is less known for his works on pedagogy and didactics. He has many activities in this area, but he never consolidated them into a consistent theory (see Siemsen 2014). What are these "activities"?

Most influentially, he co-authored the physics school books, which were used from the 1880's to the mid 1920's in larger parts of the German speaking countries. He also wrote a teacher instruction for the school books (see Hohenester, 1988, Ernst Mach als Didaktiker, Lehrbuch- und Lehrplanverfasser. In: Haller, R. & Stadler, F. (Eds.), Ernst Mach Werk und Wirkung, Vienna: Hölder-Pichler-Tempski; part-translation Siemsen 2012, 2013). He was also founder and co-editor of a teachers'journal in science education *Zeitschrift für den Physikalischen und Chemischen Unterricht*. In this function, he wrote several articles (like the one translated here) and small "thought experimental "descriptions to be used for teaching. Unfortunately, nearly all this material has not yet been translated into English (collected in German by Koller, 1997, Kommentare zu den physikdidaktischen Schriften Ernst Machs, Diploma Thesis at the Karl-Franzens-Universität Graz, supervised by Adolf Hohenester). Furthermore, he used his pedagogy to transform the thoughts of his students. William James considered Mach's lecture as "the most artistic lesson I ever heard "(see Thiele 1978, *Wissenschaftliche Kommunikation: Die Korrespondenz Ernst Machs*, Kastellaun: Henn; Siemsen 2014). The following article gives an account of the *erkenntnis*-psychological implications of Mach's pedagogy.

[3] **Translator's note**: Mach's clear distinction and well-known criticism of metaphysics can be found in this statement. From a Machian perspective, current science teaching is full of metaphysical errors, which are not recognized as such. If students and teachers do not "understand" the inconsistencies taught to them, one cannot thus blame them for being confused about what is confusing.

[4] As such an outgrowth I have to call the view, which an eminent natural scientist, who at a time also had been a proficient school teacher, had advanced towards me. He stated that in geometry

elements of Euclid were seen as a model of scientific method. At the time, one barely considered that this method, which may have proven of excellent value as a means to train the reasoning power and logically educating adult men with extended practical and scientific geometrical knowledge, would be completely inappropriate for introduction into geometry.[5] Criticism[6] cannot already start, where secure conceptualizations are still completely missing. Criticism, which does not produce, but only assorts what is given, is by no means the whole of science, but it is a means for stabilizing it.[7]

The goal of the teaching is without question not only psychological, but also logical. Not only a vivid visualization of the facts should be gained, but also an arrangement of the concepts achieved, which allows for the most parsimonious expression of them. It nevertheless seems to be clear that the order of the concepts can only occur when and to the extent that concepts are gained in the first place. If, as it often happens, it is required that teaching should already begin with full sentences [*Sätze*] and as well continue in sentences, from which later (also at reaching the teaching goal) nothing is to be corrected, then one already presupposes, I think, the attainable goal, which one seeks, as already having been reached. One expects from the student an overview, a familiarity of the contents, a training of abstraction, which is not only non-existing, but cannot possibly be existing yet; what at best can be the end of the activity, one wants to begin with. This procedure – the counter image of the historical way of development – I can only consider as mistaken.

It will not be denied that a word has only value and meaning by the conceptions it awakens, by the psychological contents given to it, without which it just remains empty sound. This content is very different, depending on the conceptual richness of the speaker and of the addressed person. If now the teacher, to whom all the teaching contents is present, mounts a sentence adapted to his concepts to his own satisfaction; so therein is – if it happens unconsciously – definitely an error regarding the person on whose satisfaction teaching foremost depends; if it happens

---

teaching, one had to accustom the student to judge correctly from a false figure from given premises. Admittedly, such a procedure can be exceptionally quite useful in order to make the difference between the conceptualized perception [*Anschauung*] process from the logical process, which basically happens in the *argumentum ad absurdum*; but where would one end by systematically leading to mistrust the conceptualized perception?! – Another time I heard in a group of teachers the statement that a certain topic could not be included into elementary teaching, because the definition of the basic concepts was not scientifically completed. – Also J. K. Becker seems to turn against such outgrowths, when he underlines that the proven truths are in no way better than the immediately perceived.

[5] Luckily, nobody falls into the hands of a didact proceeding Euclidically without themselves having at least some initial geometrical concepts.

[6] **Translator's note**: Mach is here referring to Kant's and Herbart's method of criticism. Criticism is optimizing by reducing mistakes. In another article, Mach explains that first one needs to have a relatively stable "world view", before it can be "optimized". Children are initially lacking the stable world view (a basic model).

[7] This circumstance is illustrated by nothing better than the comparison of the transparency and fruitfulness of modern geometrical methods with the clumsiness and barrenness of the Euclidean.

consciously, it is a didactical dishonesty.[8] For the student, a prematurely applied completeness and logical finesse must be useless and worthless, yes often even distracting.

If one sticks to this claim, it is practically impossible to start teaching or to proceed, without continuously violating against didactic usefulness. The simplest sentences then become untenable, as the following examples show:

"A body, which illuminates without the mediation of another, is called self-luminous." The teacher will now immediately notice that – according to today's understanding at least – every body can only illuminate through the mediation of the ether. Wouldn't it be most unpractical to interrupt the simple thought of the student by some reservation, at this point at which the student does not think about the ether and does not need to do so?

"A body, which taken in-between the eye and another body, does not hinder the excitement of light perception through the latter, is called transparent." According to this, a glass prism with a sufficiently large refraction angle would not be transparent. How quirky would a sentence have to appear to the student, if one would also take such a case into account?

"The pressure of a heavy body on the surface is called its weight." One would actually have to say "on a surface at rest". Strictly speaking, also that would not be unobjectionable, but should be "on the in a vertical sense not accelerated surface", against which one could still object to on a higher level.

These examples could be proliferated at will. Who had – for example when composing an elementary teaching book – not felt the conflict between the requirements of the didactic utility on the one hand and those of science and logical precision on the other? To satisfy both requirements to the same degree is simply not possible.

Such difficulties are naturally resolved by gradually proceeding from the simpler to the more composed, if one introduces the necessary completeness and precision after sufficient psychological preparation. A logical contradiction would only exist, if the student, after being better taught, would still see the introductory sentence as a complete and generally valid instruction. At the end of teaching, the introductory sentence has also acquired a different meaning for the student. Also he acknowledges it as provisional.

The adaptation of the thoughts in the process of scientific development enables us to complete a partially given fact in thoughts, i.e. seeing an incoming light beam the we can anticipate the refracted one, to find the induced current in the neighboring conductor of a moved conductor, etc. The result of this adaptation can thereby linguistically be formulated: If A is, so is B. But as a fact in general is not exactly repeated, so such a result can only be gained by a process of abstraction, which

[8] Reading the writings of some eminent researchers (e.g. Gauss), to the same degree as one enters, one feels all the more, that they have not written them for the reader, but for their own satisfaction. By this, some such text has acquired a nearly enigmatic form. One can understand the sentences of them but in one specific way, if one succeeds in understanding them at all. This way of fixing a completed knowledge is also a masterpiece, but by no means a didactical one. A few introductory words about how the researcher has reached his results, in general saves the reader some major work.

results in a series of facts with coinciding attributes. The economy of replicating the facts in the thoughts already necessarily compels to this. By the thoughts also seeking to sufficiently replicate the differences of the facts, also the necessity then arises to seek the differentiating attributes of the facts. Natural research consists of this gradual separation of the coinciding and differentiating attributes; a process which one could call classification. If the facts are so close, that the decisive [*massgebenden*] attributes of them only differ by the amount of equal parts, into which they can be dissected, so the further classification can take place according to this number of the parts. The measurement and counting or the intermediate counting, the calculation, i.e. the mathematical treatment commences. The advantage of the latter consists in the immediate ability to refine the classification infinitely. Rightly, one considers the adaptation of the thoughts, which has advanced thus far as being essentially completed.

The advancement of the before mentioned classification process requires a vivid envisioning of the facts. Wherein the behavior of electrical, magnetic and heavy bodies coincides (reverse square law), and wherein it differs, can only be noticed by one who is familiar with the facts. Who is psychologically prepared by the demonstration of a continuum of cases of light refraction (i.e. air – glass) will easily notice the similarity of them (that both rays lie perpendicular in the same plane and larger arrival angles correspond to larger refraction angles) and also the difference (that each arrival angle corresponds to a different refraction angle). One has arrived with the mathematical classification, if one can attribute each special arrival angle a special refraction angle, for example by making a chart. If one can see that the chart can be replaced by the formula $\sin\alpha/\sin\beta = 3/2$, so this initially seems like a practical simplification. But we have found a new similarity of all cases of refraction, if it turns out that in all of them, is manifested the same relation of the speed of light in air and in glass. The order established gradually in such a way will probably be better understood and valued than if it would be presented in a completed form – for instance by the immediate introduction of the refraction law – which would be consistent with a logical, but not with a psychological process.

It should not remain unmentioned that for the accomplishment of the aforementioned classification the psychological preparation is all the more necessary, as the coinciding and differentiating attributes often are not gained by immediate perception/conceptualization [*Anschauung*], but through an abstraction based on laborious activity, an activity which should be well trained.[9] The abstraction "refraction exponent", "moment", etc. will only be constructed by the one, who really calculated the refraction occurrences, the occurrences of equilibrium, etc. One can barely disrupt the abstraction process more effectively than by prematurely making use of it.[10]

[9] I think that one can agree to what is stated in the text, even if one does not agree to the view on abstraction, which I have detailed elsewhere (*Beiträge zur Analyse der Empfindungen*. Jena 1886. pp. 149). Nobody doubts that for instance in mathematics, the understanding is based on the practicing of the operations.

[10] In my youth I was repeatedly in the position to provide elementary teaching and could many times see for myself the barrenness of the pressing for premature abstraction. If, for instance, I

The solution of a problem consists in the completion of a currently insufficient classification, by either finding a new more general similarity or a more detailed differentiation. So the discrepancy, which seems to lie in the movement of a body, when pushed on a horizontal path or thrown upwards it is slowed, while a falling body is accelerated, is resolved by the recognition [*Erkenntnis*] that accelerating circumstances apply to all these cases. The prismatic spreading of a white ray into a fan of colors seems to be a contradiction of the law of refraction, but explains itself by the finer differentiation of the refractive index of the colors. Also the solution of a problem, if it is to be valued and understood, needs to be prepared psychologically. Even the obscurity, the discrepancy, which comes before the solution of the problem, should be felt. The solution should not appear ready, before the problem has appeared, but rather become gradually. Thereby it also becomes clear that not every produced sentence can and should be indefeasible from the point of view of the resolved problem. Here applies in detail what has been stated about the application of teaching in general.

Even if the adaptation of the thoughts to the facts, i.e. the knowing of the facts is the actual goal of natural science, this goal cannot be accomplished without finally also satisfying the requirement for an economical ordering of the thoughts. From this economical requirement, the logical requirement, that is, the requirement of consistency, is a part. It would be a bad economy of a completed area of knowledge, if it would require continuous correction and improvement. The requirements of economy nevertheless go further than those of logic, which in a certain way only provides a negative regulative condition. One could state quite comprehensively the goal for natural science and natural science education as: The adaptation of the thoughts to the facts and the thoughts to each other.

I would now like to summarize my opinion in the following sentences:

One should in teaching first and foremost proceed psychologically; only secondarily and as much logically, as this is enabled through the psychological preparation so that it becomes a need.

New concepts, theories, hypotheses, solutions of problems should only be introduced, when the need for this is felt in order to be able to master the topic.

For each sentence, which appears during teaching, clarity and explicitness, but in general not indefeasibility from the point of view of the goal of teaching, should be required.

---

provided the question for able children, who could already count quite well: How much is 5 + 3?, so I got no answer. But the answer was immediately provided for the question: How many are 5 nuts and 3 nuts? Also for my children I have often observed that the abstractions, which I had in vain tried to induce, occurred a few days later just on their own, sometimes in a completely unexpected way. I think that also in higher education, without noticing, we often commit very analogous errors. – The phenomenon (mentioned in this journal, [*Zeitschrift für den physikalischen und chemischen Unterricht* III, p. 111], that so many of the most important French mathematicians of the eighteenth century were technicians by training, finds its explanation in this circumstance. The technician has to concern him/ herself with many details; his/her abstractions appear later, but often more powerful than at the study of pure theory.

Part III
Curriculum Development and Justification

Chapter 8
Scientific Knowledge as a Culture: A Paradigm for Meaningful Teaching and Learning of Science

Igal Galili

8.1 Introduction

Science education research in part studies the ways in which scientific knowledge is represented for teaching and learning purposes. Such a goal naturally seeks to be informed by the most representative and essential features of scientific knowledge as established by research in history and philosophy of science (HPS). Though educators share many views in this regard, there is controversy regarding some features which are of principal importance (Matthews 2012; Lederman et al. 2014): objectivity-subjectivity, theory-experiment, theory dependence of observation, tentativeness-certainty, theory-model and theory-law relationships, etc. A recently published HPS&ST *Handbook* (Matthews 2014) represents the wide breadth of the pertinent discourse in this regard, and this essay touches on some of it in relation to the new inclusive framework of curricular contents oriented to Cultural Content Knowledge (CCK).

The problematic of this discourse stems from the complexity of science teaching and the multidisciplinary nature of research in the field. Science teachers require knowledge of subject matter, pedagogy, cognitive science, history and philosophy of science (Fig. 8.1). Commonly, the first three are addressed in pre-service programs of teacher training. Yet, even a basic knowledge of history and (especially) philosophy of science is very often totally lacking in such programs.[1] In such a situation, teachers' knowledge of the philosophy of science is inevitably superficial and this makes them an easy prey of various trends of superficial philosophical thought.

Seeing frequent confusion regarding epistemology among teachers encouraged us to look for a curricular framework, which could protect the practitioner providing

[1] For instance, this is the situation in Israel.

I. Galili (✉)
Science Teaching Center, The Hebrew University of Jerusalem, Jerusalem, Israel
e-mail: igal.galili@mail.huji.ac.il

M.R. Matthews (ed.), *History, Philosophy and Science Teaching*, Science: Philosophy, History and Education, DOI 10.1007/978-3-319-62616-1_8

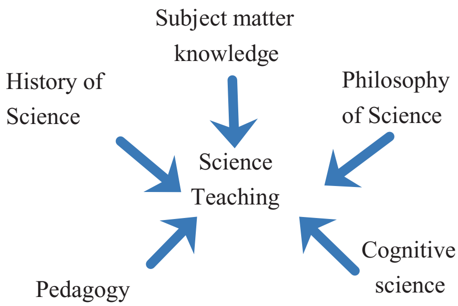


Fig. 8.1 Areas of proficiency required from science educators

a wider a more mature representation of scientific knowledge – metaknowledge, drawing on basic aspects of HPS. The core idea of the suggested change is to consider *scientific knowledge* as a kind of *cultural system*, a discourse of ideas rather than a univocal discipline. This perspective mediates between scientific knowledge and the learner constructing understanding of science.

In the following, we will first depict science knowledge composed of a few fundamental theories as a special type of culture, so that disciplines become discipline-cultures (Tseitlin and Galili 2005). We will review applications of this paradigm to the contents of science curriculum: presenting scientific revolutions, involvement of HPS, conceptual change of students learning science and their interests in science. The essay proceeds and depicts the implementations of CCK (Cultural Content Knowledge) perspective in three curricular approaches: CCK based curriculum, conceptual excursus and summative lecture. Finally, the cultural perspective expands on some epistemological issues suggesting complementarity and integrated account in order to clarify and refine such epistemological oppositions as theory-model, objective-subjective in scientific knowledge.

8.2 Knowledge as a Culture

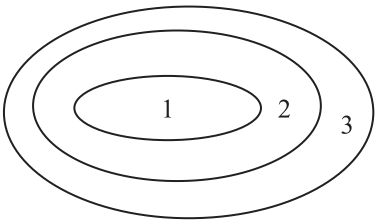
The term *culture* is extremely inclusive. It designates the entirety of human products (Tylor 1871/1920). Hofstede (1991) reduced it to a subset of material and spiritual products with the productive activities distinguishing one group from another. Thus, science is clearly distinct from history, religion, philosophy, arts, even if it is often interwoven with them. It employs a different methodology, possesses different goals and values. It is common to consider science as interacting *with* culture in specific social aspects (e.g. Bevilacqua et al. 2001). Other researchers elaborate the features characterizing the activities, behavior, internal relationships of scientists as a social group (e.g. Latour 1987). Still another popular meaning of culture considers ethnical traditions, habits of different civilizations in the ways they accounted for nature, the kind of knowledge and knowledge production different from those adopted in the western science (e.g. Aikenhead, Aikenhead 1997; Ma 2012; Liu 2015).

Physics knowledge, as we know it, is composed of a few fundamental theories, each presenting an organized and internally coherent set of interrelated concepts, principles, laws and their derivatives all together describing and interpreting features of world organization in a unified structure (Heisenberg 1959/1971; Weizsacker 1985/2006; Weinberg 1992).[2] Each such theory presents a "picture of the world" (Einstein 1918), valid not globally but in a certain area of experience and degree of accuracy/reliability.

There is a specific perspective in which knowledge itself is considered as a culture (Lotman 2010). Lotman distinguished two types: the culture of rules and the culture of texts. Within the first type, the well-defined rules regulate relationship among knowledge elements in certain area, making clear their correct-incorrect status (e.g. jurisprudence). The culture of texts allows grouping knowledge elements around canonical exemplars (e.g. art). One may consider scientific knowledge as a *culture of rules* composed of disciplines such as mechanics, electromagnetism, thermodynamics, etc. Each group of knowledge elements affiliated with a discipline can be represented by a fundamental theory structured in terms of nucleus-body-periphery – "discipline-culture" (Tseitlin and Galili 2005). Such representation is not only hierarchical but also reflects scientific knowledge as inherently discursive, yet specific in validation in terms correct-incorrect and including epistemological norms. Considering scientific knowledge as a culture creates an encompassing and adequate picture of such knowledge. It may serve as a guidance in the selection relevant HPS materials in the curriculum design, clarifying their role and possible involvement. This approach was exemplified in developing the historico-philosophical perspective on teaching optics (Galili 2014).

Discipline-culture codifies scientific theory in a tripartite structure (Fig. 8.2). Its first area, *nucleus,* includes fundamentals – the principles of ontological and epistemological nature, paradigmatic model and basic concepts. The second one, *body knowledge*, includes the elements subdued to the nucleus. They could be derived from and reduced to the fundamentals as well as being empirical and non-contradictive with the nucleus. *Body knowledge* incorporates more specific laws, secondary concepts, explanations of particular phenomena, experiments (actual and

Fig. 8.2 The structure of discipline-culture: *1*-nucleus, *2*– body knowledge, *3*- periphery



[2] Though we address the fundamental theories of physics, the stated regarding theory representation holds also regarding theories in biology (e.g. theory of evolution) and chemistry (e.g. classification of elements).

thought), technology, etc.[3] To better represent the nature of scientific knowledge as a culture, one should, however, expand and include elements of a third type – *periphery*. The elements of periphery are at odds with the pertinent nucleus. Periphery includes challenging problems and alternative accounts. By challenging certain nucleus, the periphery of the correspondent theory determines the meaning of the nucleus as well as informs about the boundaries of the theory so often remained implicit and not known to the novice. In that, periphery touches on the tradition of apophatic and comparative approaches in philosophy (e.g. Libbrecht 2009). Scientific knowledge codified and structured in terms of discipline-cultures, is defined as cultural content knowledge (CCK) and establishes a framework of the new type of science curriculum (Galili 2012).

Furthermore, since learning scientific concepts could be considered somewhat similar to the process of learning of a foreign language (Vygotsky 1986) – the learning "from outside" – identifying scientific knowledge as a culture cannot be left for students to discover; instruction should introduce the codification of knowledge and its structure.

8.3 Cultural Content Knowledge Advantages

8.3.1 Scientific Revolution and History of Physics

We can apply the introduced structure to representation of conceptual change taking place in science during scientific revolution, replacement of the fundamental theory. Instead of seeing this process as a sequential exchange of theories, each dismissing the previous, CCK suggests an inclusive and more realistic image incorporating competitive ideas. This is because:

> At almost any period in history, one can find a vast range of ideas existing simultaneously. The important question is which of the variety of ideas available at an earlier period got adopted and transmitted to later periods, and thus shaped later interpretations. (Giere 1999, p. 88)

Consider, for example, the theory of how the world is organised. Its first scientific account took the form of the geocentric theory. Its *nucleus* included principles of Aristotelian physics, the paradigmatic model of concentric spheres, fundamental concepts (circular motion, spherical universe, the basic elements, etc.). The *body knowledge* of that theory included working models of Eudoxus and Apollonius,[4] auxiliary concepts (epicycle, equant), accounts of seasons, equinoxes, eclipses and other

[3] This definition excludes identification of a theory as either syntactic (based on axioms and theorems) or semantic (based on models) type (van Fraassen 1980, p. 44; Giere 1988, p. 48), incorporating knowledge elements of both types in addition to principles, concepts, experiments, epistemological rules, etc. In fact, it depicts a theory as it is used and taught in physics class: classical mechanics, electromagnetism, thermodynamics and so on (Tseitlin and Galili 2005).

[4] For simplicity, we may ignore here the mismatch of epicycle-based model with Aristotelian principles, which caused Lakatos to introduce *protective belt* around the core of the theory (Lakatos 1978).

phenomena as depicted in Ptolemy's *Almagest*. The body knowledge included collected data, instruments (quadrant, Jacob's staff) and methods of measurement (parallax, shadow patterns). Importantly, however, the rival (heliocentric and Earth spinning) accounts of Pythagoras, Heraclites, and Aristarchus were present from the beginning establishing permanent debate (Ptolemy 1952, pp. 6–14; Heath 1966). Various scholars continuously introduced new elements of periphery through the period of two millennia. The increasing tension between the nucleus and periphery caused the revolutionary change, a breakthrow and rearranging of elements: during the Copernican revolution, the heliocentric model moved to the nucleus, and the geocentric model – to the periphery. The body elements transformed to adjust the new nucleus.

Importantly, the elements of the new and old knowledge were interrelated within one system. One may get this spirit of conceptual unity and continuity from Einstein's perception of his contribution to physics theory. He wrote to his biographer (quoted in Miller 1986, p. xx):

> With respect to the theory of relativity, it is not at all a question of a revolutionary act, but of a natural development of a line which can be pursued through centuries.

CCK-based description visualizes this pursuit in the space of scientific discourse, displaying the meaning of crisis and following revolutionary change as described by Kuhn (1957, 1970). Yet, in the *cultural* perspective, the knowledge elements of the old nucleus are preserved after being refuted. They remain within the horizon of the new theories of the world organization.

8.3.2 Theories Relationship

The controversy of fundamental physics theories is often addressed by claiming their *incommensurability* – an essential mismatch of the scientific paradigms (Kuhn 1970). The tripartite model of discipline culture allows clarification of this relationship. In particular, the nucleus of one fundamental theory ought to be located in the periphery of the other (Fig. 8.3). Yet, at the same time, the body areas of these theories may overlay representing the cases where the same phenomenon or problem is treated by the two theories producing *commensurable* results.

For example, in the limit of low velocities both classical and relativistic mechanics provide physically equivalent results despite the essential contradiction between the nuclei of these two theories. The tripartite structure illustrates the meaning of the

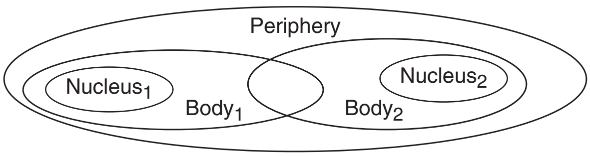


Fig. 8.3 Representation of relationship between two fundamental physical theories that contradict each other with respect to their fundamentals but may consider the same subject matter

principle of correspondence in physics knowledge. It is in this sense that continuity of scientific knowledge is maintained in science showing its cumulative nature as one of its major characteristics. Physics knowledge includes different theories, complementing each other. They establish relationship known as family resemblance, sharing some features and different in others. It allows to more advanced theories, to draw on the old accomplishments, problem solutions, rather than replacing altogether the previous knowledge. CCK envisions this type of relationship clarifying the nature of scientific holism and refining the metaphor of "patchwork" for scientific knowledge (Cartwright 2005). It is inadequate to represent scientific knowledge as a collection of non-related different pieces. Structuring the multiplicity of knowledge elements in a conceptually related web leads students to establishing *metaknowledge* defined as the knowledge of science as an organism in terms of its global features (Novak and Gowin 1984). CCK does it in terms of the tripartite structure.

8.3.3 Students' Learning

The tripartite structure of CCK suggests ways of representing individual conceptual change in learning science. Posner and associates (Posner et al. 1982) saw this process as similar to conceptual change in science and stated the epistemological conditions for that process to go – dissatisfaction, ineligibility, plausibility and fruitfulness. The individual conceptual change will be represented, then, in similar way to the change of the collective knowledge, as an exchange of contents between nucleus, initially containing naïve conceptions, and the peripheral contents created by the instruction. The implementations of students' naïve conceptions create corresponding body knowledge, which serves as a barrier for any change of the nuclear contents. The new knowledge due to instruction enters the periphery first. During the required conceptual change, the new concepts penetrate the nucleus and the naive ones move to the periphery.[5] Yet, facing a novel situation, students may retrieve the old contents and apply them again (Galili and Bar 1992). The metaphor of a breakthrough through the barrier of body knowledge may explain the difficulty of conceptual change, its essential difference from replacement as old software in a computer.[6]

Furthermore, periphery knowledge stipulates meaningful learning by creation of a "space for learning" (Marton et al. 2004). The periphery creates conceptual variation with respect to the goal of instruction. For instance, the genuine understanding of Newton's First Law as the cornerstone of mechanics[7] requires addressing alternative

[5] Since 1982, the conditions for conceptual change were revised to include other factors. This, however, does not change the idea of using triadic structure to visualize the conceptual change as a breakthrough and elements transfer between nucleus and periphery.

[6] The factors instigating the breakthrough are compared, thus, to the difference of potentials between nucleus and periphery.

[7] Beyond being a special case of the Second Law, as often stated in disciplinary instruction (e.g. Galili and Tseitlin 2003).

accounts for motion – those by the Aristotelian and impetus theories. It is through identification of nucleus contents and their comparison with alternatives that conceptual change takes place both in the history of science and in individual learning.

In other words, by comparison of conceptual accounts, students may learn through considerations similar to those of scientists who changed their mind in the past (e.g. Galili 2015). The awareness of such changes is metalearning. CCK stimulates students' metalearning due to the created metaknowledge:

> Learning about the nature and structure of knowledge helps students to understand how they learn… Metalearning and metaknowledge are two different but interconnected bodies of knowledge that characterize human understanding. (Novak and Gowin 1984, p. 9)

8.3.4 Physics Curriculum

The CCK paradigm transplants easily to physics curriculum. In common teaching, the theory-based superstructure of physics knowledge is often barely emphasized. Instead, a sequence of concepts, laws, models, instruments, experiments, problems to solve and phenomena to explain flood the learners with a flux of knowledge elements without clear organization in a hierarchical structure, in effect promoting the image of a toolbox, or even a "patchwork" (Cartwright 2005). Physics educators often unfold the knowledge from simpler to complex as if building a unique and homogeneous construction.

The learner often gets an impression of a proportional accretion: the more one learns, the more one knows – more models, solved problems, explained phenomena, concepts and laws. Principles are often barely distinguished from laws which endlessly multiply themselves along the course. This perspective in which the laws might appear as "…neither universal nor necessary – nor even true" (Giere 1999, p. 90) is refined by discipline-culture organization. Indeed, physics laws are not universal and hold in specified areas of validity. Yet, the physics knowledge is composed of a few fundamental theories, structured hierarchically. They are much more than "rules for model construction".[8] Although different, they are related, epistemologically and ontologically. The diminished status of a theory in science curriculum may impede adequate appreciation of scientific knowledge as a culture.

Instead of a sequential presentation of non-interrelated contents, curricular designers may point to the triadic affiliation of each element of knowledge. We may learn of such approach from Newton. Dealing with specular reflection and refraction laws, he placed them in the nucleus of his *Opticks*. At the same time, in his *Principia,* the same laws appeared as elements of body knowledge: they were derived from the general principles of mechanics. Similarly, presenting thermodynamics one may place the state equation (Mendeleev-Clapeyron) in the nucleus as an empirically

[8] van Fraassen (2008, p. 266) says: "A well-constructed scientific theory will tell a story, a narrative in which the *why* is as clearly explained as the *what*, and we come to understand not only 'what happens' but 'what is really going on'".

based law, whereas in statistical physics the same law would be affiliated with the body knowledge backed by its microscopic underpinning.

The CCK approach emphasizes the nucleus in each theory, often missed in physics class. Thus, such contents of mechanics as space and time, relativity, interaction, inertia being ignored may mask the essential difference with their counterparts in electromagnetism.[9]

An important feature of the CCK based curriculum is inclusion of knowledge elements usually considered to be wrong or external, they are in the periphery of the considered theory. For instance, the curriculum of classical mechanics would incorporate the obsolete conceptions of Aristotelian violent and natural motion, medieval impetus. Moreover, such curriculum would point to *how* classical mechanics essentially is different from relativistic and quantum. It is also emphasized that the classical account is valid in the particular span of space, time and mass magnitudes. By variation, these extensions provide the meaning of the classical conception of motion in the unified picture of physics knowledge.

The appeal to the alternative ideas specifies HPS involvement surpassing a mere enrichment and scientific literacy. By bringing conceptual alternatives to the fore, the curriculum reveals diachronic and synchronic conceptual debates thus promoting meaningful learning of scientific disciplines.

8.3.5 Students' Typology

The tripartite structure of discipline-culture suggests a new typology of students with regard to their potential, interests and intentions. Instead of the division between scientists and non-scientists ("good" and "bad" in science) as reflecting "two cultures" (Snow 1959), students may be distinguished in their cognitive preferences towards the three facets of scientific knowledge corresponding to the three types of knowledge elements of discipline-culture. Some students may show interest in the rules of the world order (the nucleus), but remain reluctant towards their applications, problem solving, and are satisfied by being informed of the science fundamentals. Other students may prefer solving practical problems (body) taking general principles as given. Such individuals are focused on certain problems that attract them either by challenging their ambition of mastering scientific knowledge or being encouraged by their needs of different nature (e.g. social or techonological). Becoming a competent practitioner implies seeking proficiency in modeling and problem solving. The third type of students is interested in a different aspect of scientific knowledge. Facing the authoritative claims, they raise, however, a question why these laws and not others govern reality.[10]

[9]The contrast between nuclei of classical mechanics and classical electromagnetism is striking, since electromagnetism is essentially relativistic theory and employs field interaction.

[10]Allegedly, this was the question Einstein mentioned as the one he would ask God if a chance were granted.

The students of the first type – “observers-philosophers” – often meet teachers' remarks of being superficial, not practical and not serious enough. They are advised to engage in more practice, problem solving, and mastering of mathematical formalism. They are urged not to be “childish dreamers”. Taking seriously such critique, such students often leave their science class and move over to humanities. This presents a real loss for our society that badly needs an enlightened population literate in science in order to make educated decisions in a modern democratic society. Worth listening to is one of the leading physicists of our time who said:

> What is important in science (I leave philosophy to others) is not the solution of some popular scientific problems of one's own day, but understanding the world. (Weinberg 2015, p. 24)

The students who are attracted to the body knowledge – “engineers” – do not need to be pressured. They often please their teachers and are usually supported by the school administration. Such students are often shown in media as easy to present and appreciate. Indeed, they comprise the great reserve for the practitioners, normal scientists and people of technology.

The third and most controversial type of student is attracted to the periphery knowledge – where there is debate over ideas. Such students – “investigators” – often challenge the teachers with philosophical questions. “Correct” and “incorrect” subject matter becomes equally interesting and deserve attention. Since such students may impede the flow of instruction, they might face not a favorable attitude. Yet, before they are called to order, one may recollect that the archaic “philosophical” ideas of *potentiality* and *actuality* in Aristotelian physics inspired the founders of quantum mechanics, students of classical gymnasium. It was the antique idea of the Cartesian plenum that led physicists to the introduction of the field concept to account for interactions in electromagnetism. The twentieth century introduction of photons was informed by the seventeenth–nineteenth centuries debates about the particle-wave nature of light in. Recycling of ideas is a norm in physics research and virtue of intellectuality. Therefore, the students of the third type deserve support and encouragement, as they will nourish the new generation of researchers, the science pioneers producing essentially new knowledge – the extremely important role.

It is important therefore that science curriculum speaks in three voices corresponding to the three aspects of CCK, matching the interests important for the society in wider perspective. Moreover, given that people are not born with clear self-identification of their cognitive preferences, each of us must try all three aspects of scientific knowledge to detect and make the correct choice of his/her preference for future occupation, leaving aside the special value of holistic knowledge and the pleasure people receive from multi-faceted intellectuality. The evidence of relevance of the tripartite typology of students' preferences emerged from a study introducing discipline-culture in a summative lecture (Levrini et al. 2014) that will be addressed in the following.

8.4 The Ways to Provide Cultural Content Knowledge

After a certain innovation is theoretically considered, the ways to implement it become a subject of experimentation. Feasibility and the nature of impact of any innovation can be checked only through real teaching. We have explored three ways to facilitate construction of CCK in students. Their brief account follows.

8.4.1 CCK-Based Curriculum

The *first* and the most comprehensive way is a production of a CCK-based curriculum in a certain area of knowledge. We produced a new curriculum for teaching optics – a theory of light and vision – in high school and developed a special textbook (Galili and Hazan 2004). A yearlong teaching experiment was performed (Galili and Hazan 2000). The new curriculum included the unfolding discourse with regard to the nature of vision and light, the debate of competitive accounts throughout the history of science (Lindberg 1976; Galili 2014).

Our experience in teaching optics and research in students' knowledge found evidence of certain recapitulation. Recapitulation implies similarity of ontogeny of knowledge, individual development, and correspondent phylogeny, the development of the pertinent collective knowledge. In the domain of optics and vision such parallelism is presented in Table 8.1.

Optics teaching involving the diachronic discourse on the nature of light and vision caused resonance with students' ideas and beliefs. The teachers drew on this similarity in addressing the known misconceptions of students. In a way, CCK of

Table 8.1 Conceptual parallelism in optics knowledge

Historical conceptions	Students' conceptions
Pythagorean active vision (5th c. B.C.)	Active vision scheme
Euclidean dichotomy of vision and light rays (Ptolemy – 2nd c., Alkindi, 9th c.)	Rays of sight and rays of light
Atomists' conception of Eidola (moving replica, simulacrum, from the observed object) (5th c. B.C.)	Conception (scheme) of Holistic Image moving in space
Biblical dichotomy of light as an entity and light as perception (lumen-lux Latin and in photometry)	Conception of static light located in/around light sources (halo, bright sky) and illuminated surfaces and moving light
Ibn al-Haytham's theory of light and vision (11th c.)	Light comprised of rays and image projection scheme of account for optical image observed by means of light rays
Pure (white) light and colour as a pigment, attenuation/pigmentation	Pure (white) light and colour as a pigment, attenuation/pigmentation

Galili and Hazan (2000)

the subject matter vaccinated the learners through their appreciation of the evolving scientific views. We believe that even if the particular student did not develop a particular alternative conception, the learning about such was beneficial. Students' naïve ideas are often less well reasoned in comparison with historical conceptions. Therefore, comprehension of the pertinent historical debate enriches students' knowledge instigating conceptual learning. The usually vague intuitive alternative ideas become distinct in their meaning and that helps to analyse them, reveal their rationale and facilitate their refutation. This process may be compared with increasing the potential difference between the nucleus and periphery leading to a breakthrough – the required conceptual change. Our experiment showed that the suggested curriculum had strong remedial effect on students' misconceptions (Galili and Hazan 2000).

8.4.2 Conceptual Excursus

The *second* way to provide CCK we explored does not require changes in the regular curriculum and facilitates the cultural upgrading of conceptual knowledge by means of complementary studies. It suggests performing a conceptual excursus[11] to the historical consolidation of a particular concept that took place in the history of science, identifying the major steps in such process and thus establishing the space of variation of that concept in order to be truly understood. This genre is common in historical studies often focused on certain concept (e.g. Jammer 1957; Lindberg 1976). It, however, is marginal in regular disciplinary teaching-learning. We have produced several such HPS-based excursuses to illustrate the idea in educational perspective (Galili 2012). Excursuses may support students' learning in classes and teachers' training, in- and pre-service. We picked up several concepts that were interesting and relevant to illustrate this new genre. The problematic nature of the chosen concepts (collision, motion, image, weight and inertial force) calls attention and invites changes in teaching practice. In the following, we briefly illustrate a couple of them.

8.4.2.1 The Concept of Weight

The concept of weight is of special interest in science education because it belongs to a cluster of concepts interwoven, interchangeably used and badly distinguished: weight, mass, heaviness, gravity, gravitation. Moreover, there is no consensus among physics educators regarding how this concept should be defined. In many countries weight of a body is defined as the gravitational force exerted on it

[11] The meaning we address in the notion of *excursus* is stepping aside of the major line of teaching for elaborating on a certain subject.

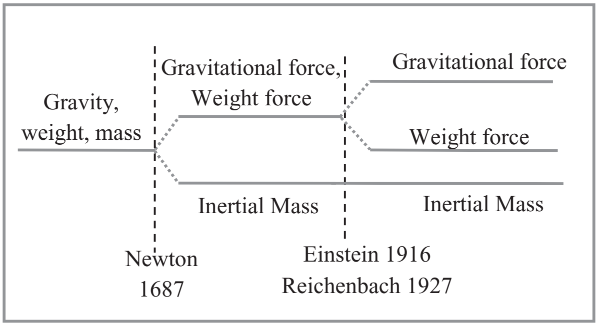


Fig. 8.4 Flowchart of the conceptual change of meaning in the conceptual cluster of mass-weight-gravitation throughout the history of science (Galili 2012)

(e.g. Young and Freedman 2004, 2012),[12] while in others, weight is defined as a result of standard weighing.[13] Physics educators argued for the latter followed Reichenbach (1927/1958, p. 223) in his epistemological analysis in light of the Einstein principle of equivalence. The debate in physics education started after King (1962) who argued for changing the definition of weight toward the operational one. The concept of weight was discussed (Galili 2001), checked in students' and teachers' knowledge (Galili and Kaplan 1996; Galili and Lehavi 2003, 2006) and experimentally tested in teaching (Stein and Galili 2014; Stein et al. 2015; Galili et al. 2017) showing numerous advantages of the operational definition of weight. Textbooks slowly change in the account of weight and weightlessness towards the operational definition of weight.[14]

Importantly, however, physics textbooks avoid discussing the available choice in the definition of weight, and do not compare between the two options, regardless the way they chose to present the weight concept and related issues (weightlessness, weight changes, etc.). The CCK orientated excursus to the subject suggests an explicit comparison between the approaches. In contrast to disciplinary teaching, the excursus followed the evolution of the pertinent conceptual understanding (Fig. 8.4), displayed the debate of scientists, their discourse and in this way revealed to the learners the rationale underpinning concept definitions in general, the need of

[12] Such is the definition adopted in the majority of the "Western" world countries (also in Australia, South Korea and many others). This approach culminates in the famous definition: "The weight of a body is the total gravitational force exerted on the body by all other bodies in the universe" (Young and Freedman 2012). The latter has no sense in modern physics epistemology being impossible either to measure, or estimate, or use in solving any problem (Galili 2001).

[13] For instance, Baruch and Vizansky (1937) in Israel, Chaikin (1947/1963) in Russia; Marion and Hornyack (1982) and Knight (2013) in the US.

[14] Hewitt 1992, pp. 176, 179–180, versus Hewitt 2002, pp.159–160; Knight 2004, pp.131–132, versus Knight 2013, pp.146–147; Resnick and Halliday 1966, p. 93 versus Halliday et al. 2001, pp. 80–81

a pair of definitions for each: nominal and operational (Margenau 1950). This requirement presents a new epistemological framework of physics knowledge introduced in the modern physics, and it is illustrated by the case of weight.

8.4.2.2 The Concept of Optical Image

This excursus lays out the genesis of physics knowledge regarding optical imagery and vision. The subject is usually studied at the beginning of optics course. The account for optical images developed in classical Greece, in parallel with the views about the nature of light. Several conceptions of optical image coexisted for years, remaining a subject of a continuous discourse[15] (Fig. 8.5). The excursus traces the evolution of understanding from the Hellenic conceptions (Pythagorean active vision, Atomists' eidola, Plato's hybrid understanding, and Aristotle's medium through transmission), to the Euclidean rays of vision, and the medieval theory by Ibn Al-Haytham (11th c.).

These accounts preceded the theory of Kepler (17th c.) and thus belong to the periphery of the currently taught light theory of rays – Geometrical Optics. The concept of light rays developed in parallel, changed its status from being the effective cause of vision, in the Hellenistic and Medieval physics, to a mere descriptive tool, in Kepler's ray and Huygens' wave theories of light. The important opposition between the intromission and extramission theories of vision held for more than 1500 years, until Ibn Al-Haytham refuted the extramission theory in the eleventh century. His own theory of image creation though was also erroneous but served as

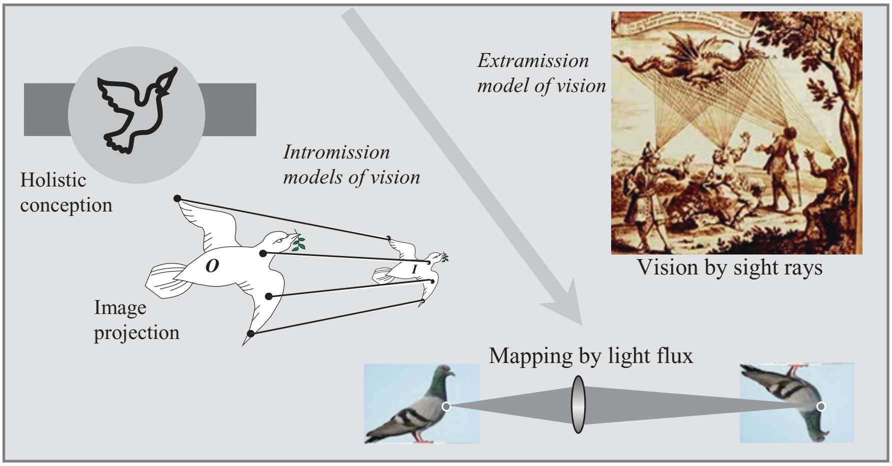


Fig. 8.5 Historical conceptions with respect to understanding of optical image (Galili 2012)

[15] Ronchi (1970, 1991), Pedersen and Phil (1974), Lindberg (1976), Russo (2004)

a vital intermediate stage before Kepler who resolved the problem within Geometrical optics – image creation by light flux, instead of single rays tracing the points of an object to its image replica (Lindberg 1976).

Similar to mechanics, it appeared that the historical conceptions are relevant for physics education. Several researchers reported and analyzed conceptions possessing clear similarity with the historical models (Table 8.1) (Guesne 1985; Bendall et al. 1993; Galili and Hazan 2000).[16] Thus, prior to optical instruction, students often show holistic understanding of optical images travelling through space, reminiscent of eidola of Greek Atomists, as well as the understanding by active vision, visual rays, similar to that by the scientists of Alexandria (Euclid, Ptolemy) and medieval Arabic scholars (Alkindi). Novice learners, after initial instruction, often show the misconception similar to Ibn al-Haytham's account for vision. It stated that "relevant" light rays, one per image point, create the image. Light rays enter the eye, refract in multiple layers and construct an image on the surface of the eye's-lens. This process often seems reasonable to learners (Galili et al. 1993; Galili and Hazan 2000; Kim 2011).

The excursus to imagery in optics creates a space of learning and furnishes genuine understanding of geometrical optics by conceptual variation and comparison amidst a range of possibilities of image creation. The excursus shows the progress of physics theories: holistic and descriptive (Hellenic), structural and mechanistic (Hellenistic and medieval light rays). The account for image changed from pure qualitative (by means of eidola) to quantitative mathematical providing image construction and a formula for its location (by means of light rays flux).

The story of the optical image touches on the nature of science with respect to its identification as a sub-culture of Western culture (Aikenhead 1997). In any event, after the first steps in Hellenic science of Greece the knowledge was promoted in Hellenistic mixed society of the middle East, and then by scientists of Muslim countries (Arabs, Jews, Christians) before its arrival to the medieval Europe (Al-Khalili 2010).

The important inference here is that different scholars, regardless their ethnicity shared a specific trend of thought and inquiry of the same subject matter. They drew on the previous research, adopted its results and further developed the relevant knowledge. The optical excursus refines the Kuhnian claim about the incommensurability of physics theories. Muslim scholars adopted Hellenic and Hellenistic science and saw it as their own. They "were not doing Islamic science. They were doing science" (Weinberg 2015, p. 70). Science clearly appears here as cumulative and continuous, preserving and developing a universal culture with no ethnic, racial or religious essence.[17]

---

[16] For a more inclusive list of citations, see Galili (2014).

[17] This claim also touches on the important trend of science education considering Western culture seeking the way to present scientific knowledge in developing countries of the post-colonial world.

8.4.3 Summative Lecture

The third way to provide CCK, *summative lecture*, though lacking the inclusiveness of the novel curriculum and the depth of historical excursus, might be, however, the most affordable and easily implemented.

In the past, David Ausubel suggested a special tool – *advance organiser* – to facilitate and fortify learning (Ausubel 1968). Before teaching a new topic, students are instructed regarding the framework of the knowledge to be considered. The instruction may include the tools to be used, such as the required mathematical formalism. Yet, the major goal in such an approach is displaying the overall idea, the concept. For example, in a biology course, introducing at the beginning the concept of natural selection may serve as an advance organizer. In physics, the big picture of the course would require addressing fundamental theories. Providing such metaknowledge as an advance organiser looked problematic in physics as there were too many unknown specific concepts. Therefore, we tried the reversed order. We designed a summative, reviewing lecture, which might be considered as an *a posteriori* or *delayed organizer*. The lecture addressed the students after they learned the contents in a traditional course.

This special type of lecture is designed to rearrange the learned materials in a theory-based structure, identifying the elements of knowledge as affiliated to three types: nucleus, body, and periphery of a certain theory. Though the lecture addresses the already known to students contents, to reach CCK, one should, besides the hierarchical classification, provide, even if only qualitatively, certain elements for the periphery of the considered theory in order to address the pertinent historical discourse. Such a lecture should create a holistic view on the course, its essential content and unifying structure, rearranging the learned mosaic of knowledge elements.

As a teaching experiment, we provided a summative lecture to three high school classes at Liceo Scientifico in Rimini, Italy (Levrini et al. 2014). Optics was chosen as an especially convenient area for testing the discipline-cultural organization since the school curriculum employs three basic theories learned in different depth: ray theory of light (geometrical optics), wave theory of light (physical optics) and photons theory of light (modern physics). To these basic theories, we added Newton's particle theory addressed at a conceptual level (Galili 2014). The four theories together created a panoramic image of optics development as shown in Fig. 8.6.

To depict the scientific discourse on light and vision a few fragments were added. Such was Newton‘s treatment of interference patterns (Newton's rings) within the theory of rays and without the interference principle (not known to Newton). He developed the ray theory and stretched it in order to include colors and color bands in thin films (Shapiro 1993). Another historical fragment added was Huygens' treatment of double refraction in crystals. It showed where Huygens was stuck, unable to recognise the transverse nature of light waves. Newton only qualitatively resolved that problem by ascribing sides to a light ray.

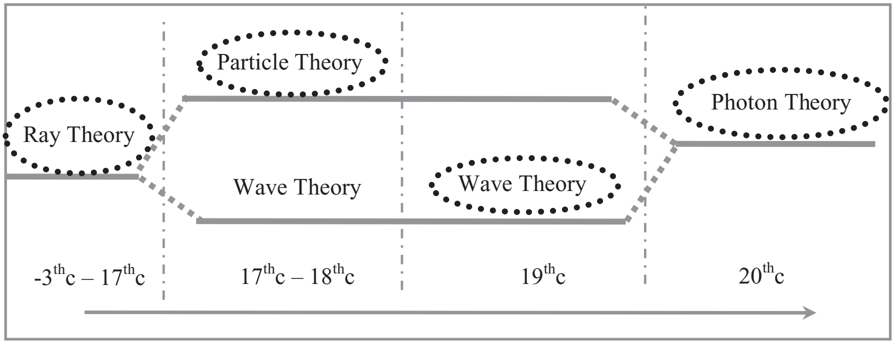


Fig. 8.6 The big picture of the development of the knowledge of light. The theories dominated in each period are marked by a point frame (Galili 2014)

The elements of optics knowledge learned and new, were affiliated in according to the tripartite codification and filled the diagrams of the kind shown on Fig. 8.7. This way a competition of basic theories was visualized: the debate on color, the account of reflection and refraction, Snell's law and double refraction, diffraction and other items populated different areas of the structure. The diagram facilitated explanation of the preference given in the eighteenth century to Newton's theory of light particles over the theory of ether waves of Huygens.

In the following, a pertinent diagram illustrated the victory of the Fresnel-Young wave theory over the Newton‘s theory of light particles in the nineteenth century. Finally, the wave theory succumbed to the modern theory of photons in the twentieth century. This review showed that each topic and feature of light the students had learned could find its location in the suggested structure and participate in a dynamic picture – recognizably human, often contentious, conditioned by context and environment, and producing a stream of knowledge development arranged in different theories.

The big picture of optical knowledge emerged in its full stature. In the case of optics, all three learned theories of light preserved their validity and coexist in present practice. Each of the basic models – ray, wave and photon – is valid in certain area of parameters (light intensity, wavelength) and level of accuracy. They serve for producing the simplest and efficient accounts, products and useful devices. The idea of knowledge progress was thus refined. Despite the confidence that the quantum theory is the most general, we account for spectacles by ray optics and for microscope resolution by light waves.

8.4.3.1 Findings of the Experiment

We applied the lecture, pre- and post- questionnaires and following class discussion (Levrini et al. 2014). We found that the tripartite organization of knowledge elements within theories was appreciated by students as helpful and informing. Novel

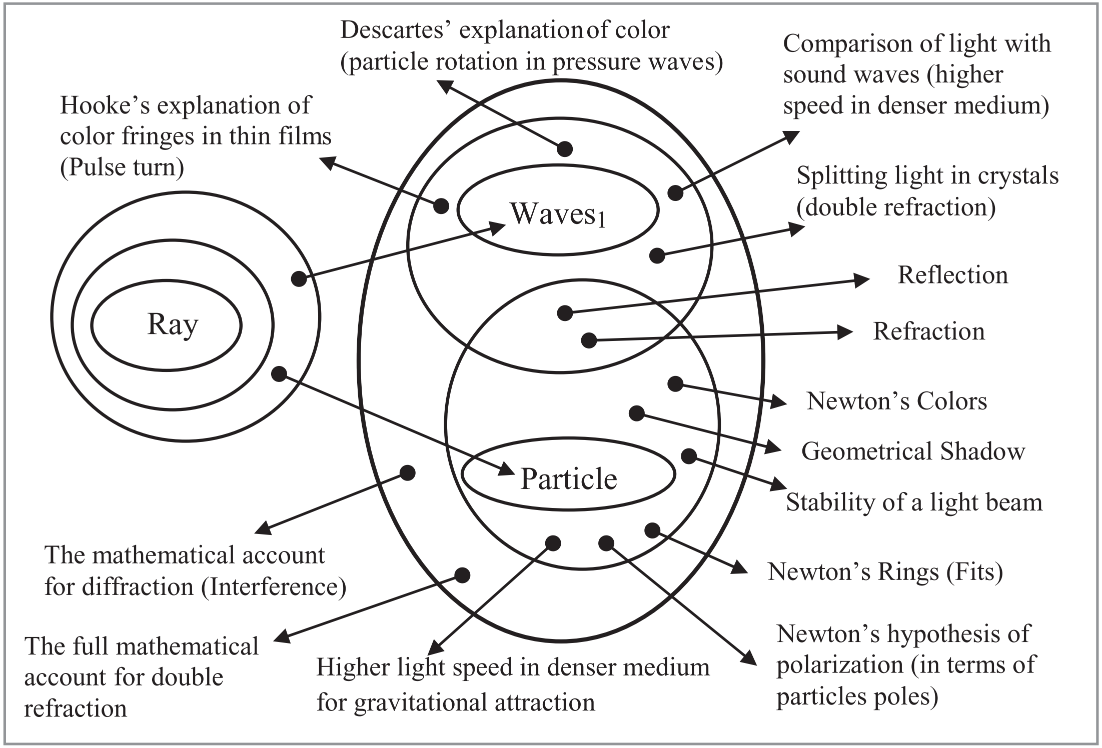


Fig. 8.7 Representation of the development of optics knowledge in the seventeenth to eighteenth centuries in the CCK perspective. It represents the competition of two theories of light stemmed from the ray theory (Levrini et al. 2014)

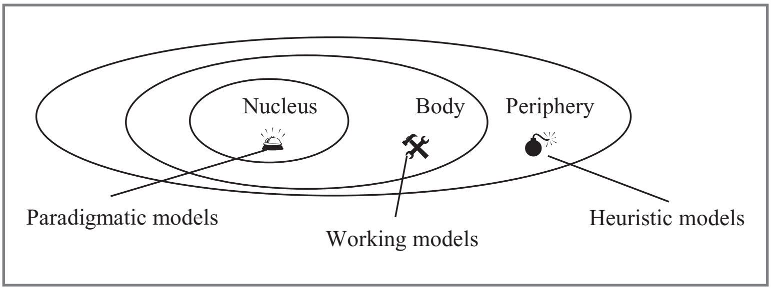


Fig. 8.8 Models may appear in all areas of theory structure

for all, it matched students' intuition. Many of them (2/3, 1/3, 1/3 in the 3 classes) said "it was not new for me…" indicating closeness to intuition and their naïve attempts to organize the multitude of laws, principles, models, concepts that they learned.[18] Students debated the relative importance of the three types of knowledge elements. They were interested in the hierarchy of the theories and their possible unification in one inclusive theory of all.

Lacking initial understanding of theories and the related role of models, the students asked for clarification of theory-model relationship. In responding to this question, different models of optical theories were affiliated to the three areas of the corresponding theories (Fig. 8.8). The models of ray, wave, photon were attributed to the nuclei as paradigmatic models. The models of thin lenses, paraxial rays, point sources were identified as working models located in the body of ray theory. Finally, the models from periphery were exemplified by photons in the wave theory used as a heuristic model.

Some students, who usually remained outside of discussions in physics class, mentioned that they were interested in the big picture of optics knowledge. Refutation of some conceptions and explanations, and adoption of others, as shown in the history and philosophy of science lessons, attracted them to physics.

The image of the subject matter as a cluster of several theories allowed consideration of the relationship of physics knowledge with the real world: does physics knowledge mirror nature exactly? Facing several valid theories of light led students away from the idea of a unique reflection toward the more adequate view of physical theory as representing a certain perspective – useful, and valid, but not identical to nature leaving space to other accounts, quite in harmony with the view that the "scientific knowledge is not absolute, but perspectival" (Giere 1999, p. 150).

Student interest and engagement that was apparent in the discussion indicated the strong appeal of the new perspective on physics knowledge applied in the experiment and its beneficial impact. Students thought about whether they wanted

[18] One may interpret this reaction to the triadic organization as a sort of cognitive resonance with the immature ideas located in the Vygotskian Zone of Proximal Development (ZPD).

to be physicists and if so, of what type – dealing with the nucleus, body or periphery of physics.

When interviewed, the teachers of the experimental classes expressed appreciation of CCK as a framework of the subject matter, unifying various knowledge elements – models, laws, experiments, etc. – in a related web. They mentioned that such inclusion of history and philosophy of science infused new meaning into the regular teaching. In particular, they pointed to the ability to display the progression of physical theories, the conceptual change in science and transitions from one theory to another. Frequent use of representative graphical, artistic, and allegorical images in the short summative lecture was seen as an appealing pedagogical tool (Galili 2013).

8.5 Epistemology and Considering Knowledge as a Culture

The impact of a cultural knowledge approach to science curriculum with respect to the epistemological aspects is of different nature because philosophy itself corresponds to a different type of culture. While the content knowledge of science comprises a culture of rules, the epistemological knowledge of science is rather a culture of texts, implying a more flexible perception of correct-incorrect opposition. Different epistemological approaches often complement each other rather than exclude.

In particular, the history of science illustrates the continuous contest of rationalist and empiricist methods of knowledge construction. Aristotle combined them in an inductive-deductive circular procedure of scientific investigation drawing on contemplation and logical analysis (Losee 1993). Platonic-Pythagorean rational analysis preceded Aristotelian. It drew on the idea of transcendent order and mathematical logic to uncover the hidden forms projecting to the perceived reality. Theory was introduced to account for and represent reality. The scientific method developed and was modified. Initially focused on theory-based speculations it was reinforced by experimentation in Hellenistic and Muslim sciences.

In the following elaboration of scientific method, medieval science introduced "prerogatives of experimental science" on top of the further developed rationalist apparatus clearly prevailed. The medieval resolution-composition method as well as nominalist-realist opposition regarding scientific concepts prepared both Baconian empiricism and Cartesian rationalism. Science always kept both approaches towards their synthesis by Galileo and Newton who produced the integrated account (Fig. 8.9). This is different from the clear hierarchy of content elements in the discipline-culture structure. For instance, in classical mechanics, the rectilinear uniform motion is affiliated to the nucleus whereas its counterparts in the Aristotelian (state of rest) and quantum (state of definite momentum) mechanics belong to the periphery.

Fig. 8.9 Plato and Aristotle in the center of Raphael fresco *The School of Athens* in Vatican (c. 1511). This image became emblematic of the Western science as having two images in its focus. The gesturing of the two philosophers is interpreted as representing integration of rationalism ("theory first") and empiricism ("experience first") (Galili 2013). (*arrows added*)

The cultural perspective unifies the accounts of discovery in the Baconian "interrogation of nature" with the constructivist creation in the scientific research program (Lakatos 1978). The combination of both approaches more adequately represents scientific practice as in Fig. 8.10.

Scientists are often inconsistent in their methodology. They may employ empiricism, rationalism, constructivism in different combinations while remaining committed to the standards of empirical verification, drawing on theory, objectivity, and open discourse. The teaching drawing on discipline-culture idea displays this plurality claiming their complementarity. The epistemological plurality influences on science curriculum as may be represented with a semiotic triangle (e.g. Löbner 2013, p. 24). In it, the disciplinary contents of a theory constitute the object vertex. The chosen philosophical dictum creates the concept vertex thus providing the object with conceptual meaning (Fig. 8.11). The object – disciplinary contents – is signified by science curriculum, the sign vertex, which features are determined by the chosen philosophical framework of the concept vertex (Tseitlin and Galili 2006). This dependence manifests itself in the emphasis and preferences given to empirical versus theoretical fundamentals,[19] deductive versus inductive organization of materials,[20] etc.

[19] Thus, one may compare the introductory physics textbooks of the Nuffield project in UK strongly emphasizing laboratory work and less the elaboration of theoretical aspects with other physics textbooks of the same level, for instance, Harvard Physics Project in the US.

[20] Introductory courses of physics are often framed in inductive organization while the corresponding advanced courses of theoretical physics are usually deductive.

Fig. 8.10 Images representing two scientific methodologies. (**a**) Discovery taken as emblematic for physics on the Nobel Price medal (names of the figures emphasized); (**b**) Constructivism as the method of modern science might be represented using the images of Pygmalion and Galatea

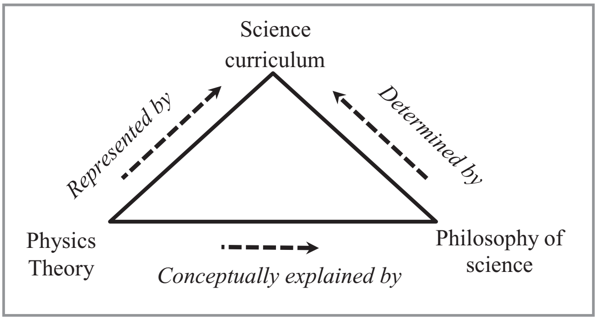


Fig. 8.11 Semiotic triangle of physics education

A discipline-cultural curriculum suggests a combined methodological perspective in exact parallel with scientists who cannot afford being restricted to one epistemology and combine philosophically different and even opposite approaches (Einstein 1949, pp. 683–684).[21]

[21] Einstein explained there: "He [scientist] therefore must appear to the systematic epistemologist as a type of unscrupulous opportunist: he appears as *realist* insofar as he seeks to describe a world independent of the acts of perception; as *idealist* insofar as he looks upon the concepts and theories as free inventions of the human spirit (not logically derivable from what is empirically given); as *positivist* insofar as he considers his concepts and theories justified *only* to the extent to which they furnish a logical representation of relations among sensory experiences. He may even appear as *Platonist* or *Pythagorean* insofar as he considers the viewpoint of logical simplicity as an indispensable and effective tool of his research."

Pragmatic, instrumental philosophy, such as that by Dewey (1938), would emphasise problem-based curriculum, learning by doing, drawing on personal experience and initial conceptions of the learner (educational constructivism) as the ways to mastering and understanding scientific knowledge. This perspective may miss the overall view, the epistemological status of knowledge elements in the theory-based structure of physics, identification of fundamentals, concept definitions, principles, and interrelations of the constituents. Those contents would come to the fore in the curriculum based on the rationalistic account of science (e.g. Frank 1957). The latter comprise metaknowledge which cannot be created in practicing standard problems, but should be explicitly taught, illustrated and discussed.

As an example, within the curricular perspective of modelling, one considers theory merely as a set of models constructed according to certain rules (semantic view). Addressing classical mechanics such approach pointed to the set of basic models (e.g. Giere 1999, pp. 110–111; Halloun 2006, pp. 140–141). However, the other contents of theory, its nucleus may be missed. Among them, the relativity principle, concepts of absolute time and space, state of motion, force definition, central interaction of point masses, etc. Thus, the mentioned set of useful models includes the uniform motion (rectilinear with constant velocity) as *one of* the basic models, next to circular and oscillatory motions. Yet, the uniform motion is much more than that. It presents a fundamental state different from all other types of motion (e.g. Galili and Tseitlin 2003, 2013). It served as one of the revolutionary claims of Newton's *Principia* following the discourse on motion of two thousand years.

As already specified (Fig. 8.8), theoretical models contribute to all three areas of theory structure. *Paradigmatic* models of nuclei may reveal the analogy underpinning the formalism of the whole theory (in Newton‘s mechanics: point particles in a void under central force interaction). Models in the body area, *working* models, mediate between the theory and reality (Morrison and Morgan 1999) as simplified subsets of the theory enabling precise account of chosen ideal systems (e.g. mathematical pendulum). Models of the periphery may be of *heuristic* type for the account of a system without conforming to the nucleus. Such models may pave the way to a new theory (Bohr's model in quantum theory or Plank's account for blackbody radiation in classical electromagnetism).

Missing fundamentals, converts teaching of physics to instruction of a craft. Ironically, such teaching could well serve prospective physicists who will construct an adequate image of physics knowledge for themselves later. Yet, the others, the much wider audience, will miss the holistic picture of mechanics, its ideas – the cultural heritage.

Similar critique could address the model-based curriculum of introductory quantum mechanics often focused on Schrodinger equation and its solutions in simple cases. Ignoring the nucleus of quantum theory, its central principles, basic concepts and specific epistemology, so much different from classical mechanics, implies students' missing the quantum picture of the world.

Apologists for a pragmatic curriculum sometimes quote Einstein (1934/2011):

> If you want to find out anything from the theoretical physicists about the methods they use, I advise you to stick closely to one principle: don't listen to their words, fix your attention on their deeds.

One may, however, pay attention that this advice addresses the *methods* used by practitioners, not the *meaning* of the theory to develop the methods on the first place. That aspect presents a goal specific for science *education*. For that, one has no other way but address both rationalist and empiricist approaches.

Another epistemological aspect is the need of integrated concept definition. We have addressed above the concept of weight in that respect. Historically, Mach was the first who emphasized the need to draw on the operational definition of concepts. He introduced a new definition of inertial mass through the measurement of accelerations in an interaction (collision) of two bodies (Mach 1883/1989, p. 218). Einstein followed him with regard to simultaneity in his theory of relativity (Reichenbach 1927/1958).[22] Yet, the initial claim of operationalism that any "concept is synonymous with the corresponding set of operations" (Bridgman 1927) was transformed to the more recent philosophical account requiring a pair of definitions: nominal and operational of the same concept (Margenau 1950). This approach might be viewed as integration of empirical and rational approaches in physical method.

8.6 Objectivity of Scientific Knowledge

Lastly, we touch on the epistemological claim of science being *subjective* which presents a cardinal attack on the traditional presenting scientific knowledge as objective in science education.[23] Normally, physicists state (Hestenes 1993)[24]:

> What makes knowledge scientific? Scientific knowledge is distinguished from ordinary knowledge by its *objectivity, precision and structure.* These distinctions are erratically maintained and sometimes missing altogether in introductory science textbooks and programs.
>
> Students cannot be expected to comprehend the structure of science until they have learned to think objectively, in the sense that they can readily distinguish between "objective" properties of physical objects and their own subjective perceptions of them.

---

[22] In physics education, the introduction of operational definitions was advocated by Karplus (1981) and Arons (1990). Essential changes might follow such change as illustrated by the case of weight concept.

[23] Though clearly a philosophical topic, it entered educational discourse as an item of NOS (nature of science). As mentioned above, the implied complexity stems from the need to learn about the pertinent accomplishments in philosophy of science and science itself in order to avoid naïve opinions regarding the nontrivial arguments of another discourse.

[24] This claim presents a commonplace in physics (e.g. Weinberg 1992, 2001), philosophy of science (e.g. Popper 1979), history of science (e.g. Holton 1985; Russo 2004; Jaroszyński 2007).

In a sharp contrast, Lederman and colleagues assert that:

> …scientific knowledge, owing to scientists' theoretical commitments, beliefs, previous knowledge, training, experiences, and expectations, is *unavoidably subjective.* (Lederman et al. 2014, p.976. Emphasis added)

The subjectivity of scientific knowledge was argued for because of its dependence on scientific theories which were considered as subjective constructs (Lederman et al. 2015, p. 695):

> …scientific knowledge is *subjective and theory laden*. Scientists' beliefs, previous knowledge, training, experiences, and expectations, in addition to theoretical commitments, influence their work. (Emphasis added)

Steven Shapin (1996, p. 165) wrote as if in answer:

> …much recent history and sociology of science that seeks to portray science as the contingent, diverse, and at times deeply problematic product of interested, morally concerned historically situated people is likely to be read as criticism of science. It may be thought that anyone making such claims must be motivated by a desire to expose science to say that science is not objective, not true, not reliable or that such accounts will have the effect of eroding respect for science.

While Lederman talks about the personal perception of scientific knowledge and individual inquiry, Shapin addresses the collective scientific knowledge, the product of inquiry process. If taken as is, Lederman misinterprets the unifying role of theory in the scientific knowledge providing an inadequate image of science as activity of separate individuals or groups in workshops, a picture reminding more art (the culture of texts) rather than science (the culture of rules) which draws on a few fundamental theories shared by the whole community. In another perspective, Lederman's confusion stems from missing the difference between the context of inquiry and the context of justification in science (e.g. Losee 1993). To avoid confusion, one needs to address the conceptual pair objective-subjective in science curriculum, exposing and refining both aspects – discipline-cultural approach.

Historically, objectivity was preserved as a norm in science.[25] It was about the account of regularity and features of Nature (object) independent of our (subject) wish. Since its foundation in Classical Greece, natural science considered objectivity as the genus of scientific knowledge and its differentia from mythology and the knowledge in other areas of intellectual activity, history, literature, etc. (Sarton 1948, p. 170). Yet, despite the long tradition, the opposite claim of science being subjective has been univocally appeared in the voluminous *Encyclopedia of Science Education* (Gunstone 2015). Critique came from Matthews (2012) who demonstrated that the claim was dubious (mixing contents) and contradicted the actual status of scientific *knowledge*. Yet, the claim of subjectivity is not new in philosophy and sociology of science revealing non-trivial subtleties. It is therefore cannot be ignored.

Commonly, the objectivity of knowledge presumes its essential independence from psychological and social factors; the latter are germane to the creation of knowledge (the context of inquiry), and even to its form of expression, but not to the

[25] See Elkana 1981; Hempel 1966; Polanyi 1962; Popper 1979; Weinberg 2001.

epistemological status of what is created (the context of justification). Scientists explain: "the way whether and how the dropped object falls is independent of our attitude to that" and such should be any scientific account. In this sense scientists state physics theories (classical mechanics, electromagnetism, thermodynamics, quantum theories, general relativity) being *objective* and dismiss their relativism (Weinberg 1992, 2001). Each of the theories is valid in certain area of parameters and depicts a certain aspect of reality; a sort of approximation in depicting reality. Yet, their objectivity suggests understanding of the stated *tentativeness* of scientific knowledge: "the approximate theories are not merely approximately true" says Weinberg (2001, p. 208). They adequately account for certain aspects of reality. *Only* such objective knowledge can be a subject of any critical discourse stipulating its *reliability* and "health" (Popper 1965, 1978, 1979; Elkana 1981; Holton 1985), providing a pledge for progress and adequate world view − much more than new devices, medicine, and weapon (Weinberg 2001, p. 106).

Commonly objective–subjective disputes regarding scientific knowledge are sometimes interwoven with true-false claims about the putative knowledge (e.g. Agazzi 2014). In their products, scientists might be wrong or leave explanation unknown, but seeking objectivity and excluding of voluntary factors in scientific theory present a common norm. The *theory-laden* analysis is intrinsic in any scientific inquiry. However, stating analysis being *theory-laden* is not equal to voluntarism. It is as correct in science as stating *experiment-laden* theory. Both comprise complementary aspects of a *reciprocal* process of scientific inquiry essential in knowledge construction in science.

The subtlety of science is in the fact that in their account of nature scientists use associative imagination in creating a system of concepts − a "free creation of the human mind" (Einstein and Infeld 1938, p. 33). Yet, those enter into a *continuous* inquiry loop in which the chosen (subjectively) concepts are going through refinement and correction drawing on experiments. Awareness of the circular iterative construction of scientific knowledge may resolve the confusion between scientific *inquiry* and scientific *theory (subjective* and *objective* aspects of science). Indeed, inquiry relies on the individual and group views, hypothesis, interpretations, and style, and therefore, it might *include* subjective or intersubjective elements. However, the scientific theory consolidates in an iterative process of evolutionary construction, empirical corroboration in the professional discourse.[26] Multiple studies independently test theory in a variety of dimensions and in back and forth interaction with reality. Together with continuous versatile attempts of falsification, theoretical and experimental, they provide objectivity of the product. As Gerald Holton wrote:

> …the metaphysical tenets of individual scientists, though often quite strong, are generally so varied, so vague, and technically inept that in a sense they cancel out, made ineffectual by the lack of a basis for general acceptance and agreement of such tenets. (Holton 1985, p.193)

[26] The problem arises when the process of scientific inquiry is presented being listed as a sequential procedure (e.g. Hempel 1966, p.11). Missing *circularity* and *iterative* self-corrective nature of scientific inquiry makes it vulnerable to the claims of subjectivity or intersubjectivity (e.g. Husserl 1978).

Therefore, inclusion of the specific historical contents in education is essential for appreciation of objectivity as emerging from the melting pot of scientific discourse. This is the approach of CCK-based curriculum, in which scientific theories appeared not as useful opinions or dogma but as products distilled in the discipline-cultural discourse. Inclusion of diachronic discourse allows tracing the arguments on the way, compare and complement theories in contest. The mentioned excursus to the conceptual history of weight and optics may illustrate such process (Galili 2014).

In our optics materials, we considered, for instance, the path of light. Heron of Alexandria in his *Catoptrics* demonstrated the rule of specular reflection: the light path presents the shortest trajectory between any two points including mirror reflection (Cohen and Drabkin 1966, p. 263). This was a piece of objective knowledge. However, the interpretation of this result by Nature seeking the most "economical" way to go, or by Nature that does nothing in vain *(natura frustra nihil agit*) was mystical. Fermat in the seventeenth century used the method of *Maxima and Minima* and advocated for the *extreme* temporal rather than spatial path (Ross 2008, p. *v*) – the objective truth. Yet, he claimed that such path expressed the "natural intention" – a mystical view. The actual measurement confirmed the Snell law of refraction as sine ratio of incident and reflection angles – the objective truth. Descartes believed that this empirical law is insufficient, as it did not *explain* the phenomenon. He provided an *ad hoc* mechanism of analogy between light and the motion of a ball being hit downwards at the surface of water (Descartes 1637/1965, p. 79). The artificial and subjective nature of this analogy was obvious. Mach called it "unintelligible and unscientific" (Sabra 1981, p. 104).

The approach of Fermat was unsatisfactory too: how and why does light "decide" in advance (!) about the extreme path? Scientists continued to seek for an objective account. Only in the nineteenth century, following the account of wave interference by Fresnel, were the subjective speculations regarding light propagation removed. Raleigh by covering odd (or even) Fresnel zones demonstrated that light did not "decide" which way to go but goes in all ways between any two points. The interference of all these beams produces the apparent light path and destroys all others. Feynman (1948, 1985) further expanded this account to massive particles. Summarizing, the *subjective interpretations* associated with the understanding of light path through the history "cancelled out" and the *objective* account emerged. At no stage, however, were scientists seize trying to reveal the objective truth about Nature. Individual scientists are not purely subjective; their "personal knowledge" incorporates *both* subjective and objective components (Polanyi 1962).

For Karl Popper, the objectivity of physics knowledge was framed using the idea of the "third world"[27] – a virtual intellectual space incorporating physical theories (Popper 1978). Possessing its own existence (spiritual reality shared through generations), somewhat reminiscent of Plato's transcendental world of forms and the realists' view of concepts in the medieval science, it contains objective knowledge of science:

[27] To be distinguished from the real world (the first one) and the personal world (the second one).

> Without claiming to solve such ancient philosophical problems, I would argue that scientific theories share those properties of rocks—stability and independence of societal setting—that lead us to call rocks real (Weinberg 2001, p. 269).

Holton (1985) introduced ideas of science-1 and science-2 for the same purpose – to distinguish between the objective core and subjective associative ideas of physical knowledge. We used this metaphor in addressing optics as a cluster of a few theories of light complementary and objective, dwelling in the "third world". Valid in different areas of space-time and energy scales, they share the objective genus.

8.7 Conclusion

Altogether, considering scientific knowledge as a culture displays the discourse of science revealing its characteristic structural features – ontological and epistemological – which are often missing in strictly disciplinary teaching. For the ontological disciplinary contents, CCK approach suggests the curriculum displaying the tripartite hierarchical structure of a *few* fundamental theories: nucleus-body-periphery, whereas for the epistemic contents, an integrated presentation is suggested addressing a *few* principal accounts as complementary instead of claiming only one view as legitimate. Such CCK curriculum reveals a big picture and broader context of scientific knowledge. It provides metaknowledge of science appealing to the broad population of learners of different interests and preferences beyond the audience of disciplinary oriented students. It frames and specifies the involvement of HPS contents, making them a curricular necessity. In doing this, it provides a paradigm matching the historical tradition of dissemination of scientific knowledge and cultural enlightenment.

Acknowledgments I am deeply obliged to Professor Robert Carson for his essential help in preparing this paper for publication. I am in great debt to Professor Michael Matthews for his never stopping encouraging support and intellectual inspiration. The anonymous reviewers helped me greatly expanding my knowledge which I sincerely appreciate and wish to acknowledge.

References

Agazzi, E. (2014). Objectivity as a replacement for truth in modern science. In *Objectivity and its contents* (pp. 1–10). London: Springer.

Aikenhead, G. S. (1997). Towards a first nations cross-cultural science and technology curriculum. *Science Education, 81*(2), 217–238.

Al-Khalili, J. (2010). *Pathfinders. The golden age of Arabic science*. New York: Penguin Books.

Arons, A. (1990). *A guide to introductory physics teaching*. New York: Wiley.

Ausubel, D. P. (1968). *Educational psychology: A cognitive view*. New York: Holt, Rinehart & Winston.

Baruch, A., & Vizansky, A. (1937). *Physics*. Tel-Aviv: Dvir.
Bendall, S., Goldberg, F., & Galili, I. (1993). Prospective elementary teachers' prior knowledge about light. *Journal of Research in Science Teaching, 30*(9), 1169–1187.
Bevilacqua, F., Giannetto, E., & Matthews, M. (Eds.). (2001). *Science education and culture. The contribution of history and philosophy of science*. Dordrecht: Kluwer.
Bridgman, P. (1927). *The logic of modern physics*. New York: Macmillan.
Cartwright, N. (2005). *The dappled world. A study of the boundaries of science*. Cambridge: Cambridge University Press.
Chaikin, S. E. (1947/1963). *Mechanics. General physics course* (Vol. 1). Moscow: Gosizdaetlstvo Physmath Literaturi.
Cohen, R. M., & Drabkin, E. I. (1966). *A source book in Greek science*. New York: McGraw-Hill Book Company, Inc..
Descartes, R. (1637/1965). Second discourse – Of refraction. In *Discourse on method, optics, geometry and meteorology*. New York: Bobbs-Merrill.
Dewey, J. (1938). *Experience & education*. New York: Kappa Delta Pi.
Einstein, A. (1918). *Principles of research*. Address to physical society, Berlin, for Max Planck's sixtieth birthday. http://www.site.uottawa.ca/~yymao/misc/Einstein_PlanckBirthday.html. Accessed 24 Sept 2015.
Einstein, A. (1934/2011). On the method of theoretical physics. In *Essays in science*. New York: Open Road.
Einstein, A. (1949/1979). Autobiographical notes. In P. A. Schilpp (Ed.), *Albert Einstein: Philosopher-scientist*. New York: Harper.
Einstein, A., & Infeld, L. (1938). *The evolution of physics*. Cambridge: Cambridge University Press.
Elkana, Y. (1981). A programmatic attempt at an anthropology of knowledge. In E. Mendelsohn & Y. Elkana (Eds.), *Science and cultures*. Dordrecht: Reidel.
Feynman, R. (1948). The space-time formulation of nonrelativistic quantum mechanics. *Reviews of Modern Physics, 20*(2), 367–387.
Feynman, R. (1985). *QED – The strange theory of light and matter*, *Lecture 2*. Princeton: Princeton University Press.
Frank, M. (1957). *Philosophy of science. The link between science and philosophy*. Englewood Cliffs: Prentice-Hall.
Galili, I. (2001). Weight versus gravitational force: Historical and educational perspectives. *International Journal of Science Education, 23*(10), 1073–1093.
Galili, I. (2012). Promotion of content cultural knowledge through the use of the history and philosophy of science. *Science & Education, 21*(9), 1283–1316.
Galili, I. (2013). On the power of fine arts pictorial imagery in science education in science education. *Science & Education, 22*, 1911–1938.
Galili, I. (2014). Teaching optics: A Historico-philosophical perspective. In M. R. Matthews (Ed.), *International handbook of research in history and philosophy for science and mathematics education* (pp. 97–128). Dordrecht: Springer.
Galili, I. (2015). From comparison between scientists to gaining cultural scientific knowledge: Leonardo and Galileo. *Science & Education, 25*(1), 115–145.
Galili, I., & Bar, V. (1992). Motion implies force. Where to expect vestiges of the misconception? *International Journal of Science Education, 14*(1), 63–81.
Galili, I., & Hazan, A. (2000). The influence of a historically oriented course on students' content knowledge in optics evaluated by means of facets–schemes analysis. *American Journal of Physics, 68*(7), S3–S15.
Galili, I., & Kaplan, D. (1996). Students operation with the concept of weight. *Science Education, 80*(4), 457–487.
Galili, I., & Lehavi, Y. (2003). The importance of weightlessness and tides in teaching gravitation. *American Journal of Physics, 71*(11), 1127–1135.

Galili, I., & Hazan, A. (2004). *Optics – The theory of light and vision in the broad cultural approach*. Jerusalem: Science Teaching Center, The Hebrew University of Jerusalem. [ISBN-965-295-026-2]

Galili, I., & Lehavi, Y. (2006). Definitions of physical concepts: A study of physics teachers' knowledge and views. *International Journal of Science Education, 28*(5), 521–541.

Galili, I., & Tseitlin, M. (2003). Newton's first law: Text, translations, interpretations, and physics education. *Science & Education, 12*(1), 45–73.

Galili, I., Goldberg, F., & Bendall, S. (1993). Effects of prior knowledge and instruction on understanding image formation. *Journal of Research in Science Teaching, 30*(3), 271–303.

Galili, I., & Tseitlin, M. (2013). Excurse to the History of Understanding of Motion – De Motu. In I. Galili (Ed.), *The Pleasure of understanding. Collection of excurses to the history of physical concepts for teachers and students*. Jerusalem: The Amos de-Shalit Science Teaching Center, The Hebrew University of Jerusalem.

Galili, I., Bar, V., & Brosh, Y. (2017). Teaching weight-gravity and gravitation in middle school—Testing a new instructional approach. *Science & Education, 26*(3), 977–1010.

Giere, R. N. (1988). *Explaining science. A cognitive approach*. Chicago: University of Chicago Press.

Giere, R. N. (1999). *Science without laws*. Chicago: University of Chicago Press.

Guesne, E. (1985). Light. In R. Driver, E. Guesne, & A. Tiberghien (Eds.), *Children's ideas in science* (pp. 11–32). Milton Keynes: Open University Press.

Gunstone, R. (Ed.). (2015). *Encyclopedia of science education*. Dordrecht: Springer.

Halliday, D., Resnick, R., & Walker, J. (2001). *Fundamentals of physics* (9th ed.). New York: Wiley.

Halloun, I. A. (2006). *Modeling theory in science education*. Dordrecht: Springer.

Heath, T. (1966). *Aristarchus of Samos*. Oxford: Clarendon Press.

Heisenberg, W. (1959/1971). *Physics and philosophy*. London: Georger Allen & Unwin.

Hempel, C. (1966). *Philosophy of natural science*. Upper Saddle River: Simon & Schuster.

Hestenes, D. (1993). *Modelling is the name of the game. A presentation at the NSF modeling conference*. Temple: Arizona State University.

Hewitt, P. G. (1992). *Conceptual physics*. Upper Saddle River: Pearson Prentice Hall.

Hewitt, P. G. (2002). *Conceptual physics*. Upper Saddle River: Pearson Prentice Hall.

Hofstede, G. (1991). *Cultures and organizations: Software of the mind*. London: McGraw-Hill.

Holton, G. (1985). *Introduction to concepts and theories in physical science.* Second edition revised by S. G. Brush. Princeton: Princeton University Press.

Husserl, E. (1978). *The crisis of European sciences and transcendental phenomenology*. Evanston: Northwestern University Press.

Jammer, M. (1957). *Concepts of force*. Cambridge, MA: Harvard University Press.

Jaroszyński, P. (2007). *Science in culture*. New York: Rodomi.

Karplus, R. (1981). Educational aspects of the structure of physics. *American Journal of Physics, 49*(3), 238–241.

Kim, Y. (2011). How many Korean science high-school students find the same scientific problem as Kepler found in optics and physiology? *Journal of Gifted/Talented Education, 21*(2), 575–589.

King, A. L. (1962). Weight and weightlessness. *American Journal of Physics, 30*(4), 387.

Knight, R. D. (2004). *Physics for scientists and engineers*. Reading: Pearson.

Knight, R. D. (2013). *Physics for scientists and engineers* (3rd ed.). Reading: Pearson.

Kuhn, T. S. (1957). *The Copernican revolution*. Cambridge, MA: Harvard University Press.

Kuhn, T. S. (1970). *The structure of scientific revolutions*. Chicago: University of Chicago Press.

Lakatos, I. (1978). *The methodology of scientific research programs*. Cambridge: Cambridge University Press.

Latour, B. (1987). *Science in action*. Cambridge, MA: Harvard University Press.

Lederman, N. G., Bartos, S. A., & Lederman, J. S. (2014). The development, use, and interpretation of nature of science assessments. In M. R. Matthews (Ed.), *International handbook of research in history, philosophy and science teaching* (Ch. 29, pp. 971–997). Dordrecht: Springer.
Lederman, N. G., Schwartz, R., & Abd-El-Khalick, F. (2015). Conceptualizing the construct of NOS. In R. Gunstone (Ed.), *Encyclopedia of science education* (pp. 694–698). Dordrecht: Springer.
Levrini, O., Bertozzi, E., Gagliardi, M., Grimellini-Tomasini, N., Pecori, B., Tasquier, G., & Galili, I. (2014). Meeting the discipline-culture framework of physics knowledge: An experiment in Italian secondary school. *Science & Education, 23*, 1701–1731.
Libbrecht, U. (2009). Comparative philosophy: A methodological approach. In N. Note, R. Fornet-Betancout, J. Estermann, & D. Aerts (Eds.), *Worldviews and Cultures*. Dordrecht: Springer.
Lindberg, D. C. (1976). *Theories of vision from al-Kindi to Kepler*. Chicago: The University of Chicago Press.
Liu, Y. (2015). Overview of ancient Chinese science and technology. In Lu (Ed.), *A history of Chinese science and technology* (Vol. 1, pp. 19–40). Heidelberg: Springer.
Löbner, S. (2013). *Understanding semantics*. London: Routledge.
Losee, J. (1993). *A historical introduction to the philosophy of science*. New York: Oxford University Press.
Lotman, Y. (2010). The problem of learning culture as a typological characteristic. In *What people learn. Collection of papers and notes* (pp. 18–32). Moscow: Rudomino.
Ma, H. (2012). The images of science through cultural lenses. In *A Chinese study on the nature of science*. Rotterdam: Sense Publishers.
Mach, E. (1883/1989). *The science of mechanics, a critical and historical account of its development*. La Salle: Open Court.
Margenau, H. (1950). The role of definitions in science. In *The nature of physical reality* (pp. 220–244). New York: McGraw-Hill.
Marion, J. B., & Hornyack, W. F. (1982). *Physics for science and engineering* (p. 129). New York: Saunders.
Marton, F., Runesson, U., & Tsui, A. B. M. (2004). The space of learning. In F. Marton & A. B. M. Tsui (Eds.), *Classroom discourse and the space of learning* (pp. 3–40). Mahwah: Lawrence Erlbaum.
Matthews, M. R. (2012). Changing the focus: From nature of science to features of science. In M. S. Khine (Ed.), *Advances in nature of science research* (pp. 3–26). Dordrecht: Springer.
Matthews, M. R. (Ed.). (2014). *International handbook of research in history, philosophy and science teaching*. Dordrecht: Springer.
Miller, A. I. (1986). *Frontiers of physics. Selected essays* (p. xx). Boston: Birkhauser.
Morrison, M., & Morgan, M. S. (1999). Models as mediating instruments. In M. Morgan & M. S. Morrison (Eds.), *Models as mediators: Perspectives on natural and social science* (pp. 10–37). Cambridge: Cambridge University Press.
Novak, J. D., & Gowin, D. B. (1984). *Learning how to learn*. Cambridge: Cambridge University Press.
Pedersen, O., & Phil, M. (1974). *Early physics and astronomy*. London: Macdonald & Janes.
Polanyi, M. (1962). *Personal knowledge. Towards a post-critical philosophy*. London: Routledge.
Popper, K. R. (1965). *Conjectures and refutations: The growth of scientific knowledge*. New York: Harper Torchbooks.
Popper, K. R. (1978). Three worlds. *The Tanner lecture on human values*. The University of Michigan. http://www.tannerlectures.utah.edu/lectures/documents/popper80.pdf. Accessed 24 Sept 2015.
Popper, K. R. (1979). *Objective knowledge*. Oxford: Clarendon Press.
Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education, 66*, 211–227.
Ptolemy, C. (1952). Almagest. In *Britannica great books* (Vol. 6). Chicago: Encyclopedia Britannica.

Reichenbach, H. (1927/1958). *The philosophy of space and time*. New York: Dover.
Resnick, R., & Halliday, D. (1966). *Physics*. NewYork: Wiley.
Ronchi, V. (1970). *The nature of light: An historical survey*. London: Heinemann.
Ronchi, V. (1991). *Optics. The science of vision*. New York: Dover.
Ross, J. (2008). *Fermat's complete correspondence on light*. Dynamis. http://science.larouchepac.com/fermat/. Accessed 24 Sept 2015.
Russo, L. (2004). *The forgotten revolution: How science was born in 300 BC and why it had to be reborn*. Berlin: Verlag/Springer.
Sabra, A. I. (1981). *Theories of light. From Descartes to Newton*. Cambridge: Cambridge University Press.
Sarton, G. (1948). *The life of science − Essays in the history of civilization*. New York: Henry Schuman.
Shapin, S. (1996). *The scientific revolution*. Chicago: Chicago University Press.
Shapiro, A. E. (1993). *Fits, passions, and paroxysms*. Cambridge: Cambridge University Press.
Snow, C. P. (1959). *The two cultures and scientific revolution*. Cambridge: Cambridge University Press.
Stein, H., & Galili, I. (2014). The impact of operational definition of weight concept on Students' understanding of physical situations. *International Journal of Research in Science and Mathematical Education, 13*(6), 1487–1515.
Stein, H., Galili, I., & Schur, Y. (2015). Teaching new conceptual framework of weight and gravitation in the middle school. *Journal of Research in Science Teaching, 52*(9), 1234–1268.
Tseitlin, M., & Galili, I. (2005). Teaching physics in looking for its self: From a physics-discipline to a physics-culture. *Science & Education, 14*(3–5), 235–261.
Tseitlin, M., & Galili, I. (2006). Science teaching: What does it mean? – A simple semiotic perspective. *Science & Education, 15*(5), 393–417.
Tylor, E. (1871/1920). *Primitive culture* (Vol. 1). New York: Putnam's Sons.
van Fraassen, B. C. (1980). *The scientific image*. Oxford: Clarendon Press.
van Fraassen, B. C. (2008). *Scientific representation: Paradoxes of perspective*. Oxford: Clarendon Press.
Vygotsky, L. (1986). *Thought and language*. Cambridge, MA: MIT Press.
Weinberg, S. (1992). *Dreams of a final theory*. New York: Pantheon Books.
Weinberg, S. (2001). *Facing up – Science and its cultural adversaries*. Cambridge, MA: Harvard University Press.
Weinberg, S. (2015). *To explain the world: The discovery of modern science*. New York: Harper Collins.
Weizsacker, C. F. (1985/2006). *The structure of physics*. Dordrecht: Springer.
Young, H. D. & Freedman, R. A. (2004). *University physics* (pp. 120, 441, 459–460). New York: Pearson, Addison Wesley.
Young, H. D. & Freedman, R. A. (2012). *University physics* (pp. 406, 421–422). New York: Pearson, Addison Wesley.

Chapter 9
Integrating Science Education Research and History and Philosophy of Science in Developing an Energy Curriculum

Yaron Lehavi and Bat-Sheva Eylon

9.1 Introduction

Traditionally, the role of the nature of science (NOS) in curriculum development is manifested by asking how history and philosophy of science (HS and PS, respectively) should be integrated into the curriculum (Rudolph 2000), whereas ideas from science itself are often regarded as the final and desired goal of students' understanding. The findings from science education research (SER) are used to inform the curriculum designers about how students learn a certain subject, what difficulties they (and sometimes their teachers) have, and what methods are most suited for constructing the students' desired understanding. How the four disciplines – HS, PS, Science, and SER - are considered in curriculum design may vary, reflecting the curriculum developers' different educational perspectives. For example, disciplines such as the history and philosophy of science (HPS) can be used to supplement the curriculum, aimed at adding cultural information or human interest, or past scientists' views on natural phenomena could be set alongside students' views as other perspectives for consideration (Monk and Osborne 1997). Class and lab activities can be used to emphasize methodological concerns, such as the identification and control of variables, to encourage students' motivation and curiosity or, alternatively, to determine "how, with what confidence, and on what bases, scientists come to know what they do" (Shapin 1992). Results from education research

Y. Lehavi (✉)
The David Yellin College of Education, Jerusalem, Israel

The Weizmann Institute of Science, Rehovot, Israel
e-mail: yarlehavi@gmail.com

B.-S. Eylon
The David Yellin College of Education, Jerusalem, Israel
e-mail: Bat-sheva.Eylon@weizmann.ac.il

M.R. Matthews (ed.), *History, Philosophy and Science Teaching*, Science: Philosophy, History and Education, DOI 10.1007/978-3-319-62616-1_9

can be used to elicit students' prior knowledge or to put constraints on the ways by which new scientific ideas can be conveyed.

Thus, the strong interrelations among science, its philosophy, and its teaching (Elkana 2000, Matthews 2015) call for considering in conjunction all four disciplines when planning a curriculum design: Philosophy of Science, its History, Science Education Research, and Science itself (PHES). This view is in accordance with the suggestion of viewing didactics as a discipline that utilizes contributions from different scholarly fields in order to improve science education (Adúriz-Bravo and Izquierdo-Aymerich 2005). Although the four disciplines often overlap and cannot be completely distinguished from each another, each of them has its own unique contribution to curriculum decision making and therefore will be discussed here separately.

In this regard, energy serves as a very good example, since scientists, philosophers of science, and science educators (e.g., Poincare 1903/1952, ch. VIII; Feynman 1964; Bunge 2000; Wolter and Martin 2002) have all been involved in the ongoing long discussion regarding the meaning of energy and its special language (Bevilacqua 2014). Evidently, the lack of consensus with regard to what is energy, its level of abstraction and what is meant by energy types/forms, conversion/transformation, transfer and conservation presents a great challenge for an energy curriculum designer who strives for coherence and consistency. For us, the philosophical discourse with regard to the experiment-theory relationship and the meaning of scientific concepts, with special emphasis on their definitions, provides essential and rich support in making curriculum development decisions.

Thus, our approach integrates all four disciplines in developing a coherent, consistent, spiral curriculum for teaching energy. We exemplify this approach by discussing how considerations based on each of the four disciplines were integrated in making curricular decisions in the development and implementation of a curriculum for teaching the concept of energy in Israel. This approach follows and extends the suggestion that HPS should be used in order to address the teaching of the concept of energy and especially with regard to teachers' training (Bächtold and Guedj 2012, 2014). Our approach led us to shift the focus of the curriculum and to put more emphasis on quantitative change in energy rather than on energy itself. The importance of focusing on changes in energy (as one concept) rather than viewing it in a static way in teaching energy has been recognized in the past (Chisholm 1992).

Our curriculum development was based on the assumption that the difficulties reported by SER are strongly related to the above-mentioned lack of consensus with regard to the "language of energy". We not only examined past studies—we also conducted our own research, with regard to teachers' concept image of energy, to help us in making curricular decisions. In order to address the challenges that our research raised, we considered all four components of PHES in constructing a new curriculum for teaching energy in Israel.

9.2 The Integrated Approach to Curriculum Design

As described above, the design of the energy curriculum was based on four pillars: (1) History of science; (2) Science; (3) Philosophy of science, and (4) Science education research. We will describe how we employed each of these disciplines in designing our curriculum.

9.2.1 History of Science (HS): Adopting Joule's Approach

With regard to the history of science, we followed the approach to curriculum design that addresses scientific ideas in their original context of discovery (Monk and Osborn 1997). Applying this approach to energy was manifested by adopting Joule's approach.

During the nineteenth century, scientists developed the idea that the creation of a certain 'power' requires the exhaustion of another. However, to become a conservation law, this co-variation in different directions of 'power' required measurable relations to a given standard (Kuhn 1977, p. 79–82). Such relations, using change in temperature of a standard object, were established by several scientists at the middle of the nineteenth century (Kuhn 1977, p. 89) with the prominent contribution of Joule who wished to compare different processes:

> In accordance with the pledge I gave the Royal Society some years ago, I have now the honour to present it with the results of the experiments I have made in order to determine the mechanical equivalent of heat with exactness. (James Prescott Joule 1850)

Thus, Joule's approach[1] led him to arrive at quantitative relations between different phenomena rather than to characterize a new entity and to attribute it with qualities such as being indestructible. Owing to his remarkable experimental skills, he discovered quantitative relations between temperature change and other phenomena: electrical, chemical, gas expansion, and change in speed (Coopersmith 2015, p. 245–252). Although at Joule's times many concepts were used to describe different processes and phenomena (e.g., living force, heat, power), his experiments laid the groundwork for using energy as one entity that can be employed in analyzing different phenomena, otherwise considered to be disconnected (Kuhn 1977, p. 77). The heating phenomenon served Joule as a standard against which he compared the results of measuring chemical affinity, electromotive and electro-magnetic forces, and even the passage of water through narrow tubes.

Furthermore, Joule succeeded in finding equivalence between different processes by which a system can change by measuring the change in temperature of an object due to such processes:

[1] We named this approach after Joule although he was one of many who contributed to the effort to arrive at a unified concept of energy via experiments (see especially Bevilacqua 2014 and Coopersmith 2015).

A change (by various processes) → ΔT (of a certain object)

Thus, for each changing variable in his experiments, Joule could relate a certain change in temperature. This, as is well known, enabled him to relate different processes to each other and to suggest a means to compare them. One can therefore interpret Joule's approach as an endeavor to quantify different processes by the same operation of measurement.

Further pursuing Joule's approach, if one measures *separately* how each process (the change in height, speed, electric charge distribution, chemical constituents in bio and non-bio systems,[2] temperature of bodies in contact, radiation or even nuclear masses)[3] affects the change in temperature, one can combine all such processes under one concept. Note that this aligns well with Joule's own interpretation and enables regarding heat (the change in energy of an object that interacts with another object having a different temperature) and work as not distinct from each other.

Thus, HS provided us with the means to clarify in our curriculum *why* we can use *energy change* as one concept for different kinds of processes. It also led us to develop low-cost classroom experiments that can be used to demonstrate Joule's approach (Lehavi et al. 2014a, b, 2016). This unitary view of energy is crucial for presenting it as a crosscutting curricular concept.

9.2.2 Science: Interpreting the First Law of Thermodynamics and Energy Conservation

Our guiding principle in employing the scientific ideas was to consider them not only as the goal of teaching but also for guiding curriculum design decisions.

This principle was manifested in interpreting the first law of thermodynamics $\Delta E = W - Q$) as representing the change in energy (left side) corresponding to different processes (right side) and making this change the focus of the curriculum (Eylon and Lehavi 2014). Thus, the 1st law was not taught at the middle school level, but rather, it served as a means of organizing the curriculum.

The various processes by which a system can change are characterized by a change in variables such as height, temperature, and speed, among others. The change in value (increase or decrease) of each of these variables characterizes a specific change (process) in the system. Such changes in the characterizing variables, each corresponding to a certain process, indicate a corresponding change (increase or decrease) in the value of the energy of the system. Such an interpretation of the first law of thermodynamics is in accordance with both Joule's approach (although he did not use the concept of energy as such) and the scientific view of

[2] Recall Lavoisier and Laplace's calorimetric experiment that showed how processes in animals are energetically (and chemically) similar to a combustion reaction.

[3] Although many of these phenomena were not known to Joule, his approach is often used for measuring the heating/cooling they induce.

energy as one entity (Moore 1993). It follows that energy, like any other scientific entity, can change only by its value. Thus, changes in kinetic energy, height energy, and chemical energy, among others do not represent changes in different forms of energy. These 'forms' are just labels that refer to the different processes by which the value of the energy of a system can increase or decrease.

Science puts emphasis on changes and processes and employs changes in the value of energy to describe them. Notably, science provides no definite method by which the energy value of a system can be determined. In fact, the energy value of a system is relative and can be determined up to an arbitrary constant (Fermi 1936). However, this ambiguity does not affect the first law of thermodynamics, since this law is not concerned with the energy value but instead, with the quantitative changes in this value. Thus, from a scientific point of view, although energy itself cannot be determined without ambiguity, since it has no absolute zero value, a change in the quantity of energy[4] can be measured and thus, it is of physical importance.[5] A good example of this view adopted by science is that the rest mass of the objects within a system is not often mentioned (e.g., in an electric circuit or when an apple falls), although it is responsible for most of the energy related to the system. This mass cancels out since only changes in energy matter (Quinn 2014, p. 18).

It is apparent from our discussion that the 1st law is not regarded by us as representing the energy conservation law. We adopted the view that in certain systems (termed isolated since any change within them is not accompanied by any change in their surroundings and vice versa) any increase in energy related to one or more processes is counterbalanced by a decrease in energy related to one or more other processes. Such a balance can be the subject of an empirical inquiry *after* we arrived at a good quantification of energy change in processes characterized by changes in different variables. In this respect, energy conservation becomes a refutable law.

9.2.3 Philosophy of Science (PS): The Meaning of Scientific Concepts and Theory-Experiment Relationships

Science teaching should have a have deep commitment to philosophy (Gilbert 2006, p. 5; Matthews 2015). Pleasingly many philosophers recognize the place of philosophy in science teaching:

> It is well known that there is a strong interaction between the philosophy of science and the science of each generation. It is less often stated clearly that there is also an interaction between these two and the teaching of science in so far as it is the philosophy of science which molds the general attitudes which form the foundations of the various theories of science teaching. (Elkana 2000 p.463)

---

[4] In the literature, energy change is often used as a synonym for energy transformation. Here we use the term solely to describe the change in the *value* of energy: its increase or decrease.

[5] See: Fermi 1936; Quinn 2014, p. 18; Reif 1967, p. 202; Reif 1965, p. 129.

However, Feigl and Brodbeck (1953, p. 5) claimed that philosophy of science was concerned mainly with describing the structure of science itself. The structure of science, not surprisingly, has also been the concern of prominent science educators:

> By linking concept clusters that have common physical variables, one can create larger structures that ultimately encompass all of physics. The approach to definitions, empirical relationships, and theoretical relationships has to be consistent among the clusters that are linked…. there is considerable freedom in the choice of quantities to be defined and derived. The exact choices that are made will determine the structure that is obtained. (Karplus 1983, p. 240)

Elkana further supports this view:

> In whatever light we see this interaction, one thing will be admitted by all; in every age it is the philosophy of science which forms the image of science in the eyes of the masses,... It is not less important that it is this philosophy which determines what is 'good science' and thus determines how it should be taught. (Elkana 2000 p.464–465).

The importance of providing meaning to data brings back Schwab's observation that the epistemology of science is not only about its procedures—it is heavily based on interpretation. This, as stressed by Monk and Osborne (1997), has implications for curriculum development since curriculum developers should be obliged to focus not merely on scientific inquiry skills but also on interpretive discussions of the data found. The curriculum should therefore include grounds on how "scientists come to know what they do" (Shapin 1992).

Karplus'comment with regard to the freedom a curriculum planner has in choosing which concepts to define and which to derive led us to also consider, in addition to developing inquiry skills, the meanings provided to concepts and how such meanings are gained. This naturally brings to fore concepts definition and their connection to theory-experiment relationships. The context of science education also calls to interrelate it to PS by stressing the important role of theories and by addressing explicitly the nature of science in the curriculum (Duschl 1985, 1990, 2000)

Moreover, since science presents a culture, learning of science presumes enculturation from inside and/or outside (Tseitlin and Galili 2005). Expanding the practicing of science presents enculturation from inside. During such a process, conceptual knowledge is constructed by experience in many contexts. Explicit and concise articulation and contemplation of concept meaning might seem less important than application of physical knowledge. This attitude is, however, natural for "normal science" (Kuhn 1970) rather than for revolutionary research. In the latter, the concept's meaning might represent the major issue of interest (Bridgman 1952).

9.2.3.1 Addressing Scientific Concepts in Relation to Their Definitions

We adopted Elkana's approach that philosophy of science can assist in choosing the 'teaching theory' for curriculum development design:

> …We should also aim at grounding our theories of science teaching in that philosophy of science which at present seems to us the most advanced. (Elkana 2000)

Traditionally, philosophy of science was largely concerned with the meaning of the scientific concepts, with special attention given to their definitions (Bridgman 1964; Copi and Cohen 1990; Hempel 1966, 1970; Margenau 1950). Schwab (1964) stressed the importance of concept definitions with regard to the structure of a scientific discipline, as well as in educational scientific epistemology (comprising syntactic knowledge and its relation to measurement) and in scientific content (substantive knowledge). He regarded concept definitions as necessary for the coherent presentation of a subject in science owing to their role in the organization of scientific knowledge.

Thus, philosophy of science was considered in our curriculum development approach since science education requires clarity with regard to the meaning of the concepts used. The scientific activity also requires the use of concept definitions in order to make such concepts useful for scientific endeavors:

> A concept is useless if it does not appear in relation to other concepts, or if we fail to support it with clear definitions. (Holton 1985, p. 221)

Many types of definitions were found to exist (Angeles 1981). However, only two of them, nominal (theoretical) and operational (epistemic), are in accordance with the fundamental schools of scientific thinking: rationalism and empiricism (Margenau 1950; Matthews 2015).

A nominal definition seeks to establish the meaning of a concept by relating it to other concepts and by listing its characteristics. Within the nominal definitions, one can distinguish between several types: textual (such as "the weight of the body is the gravitational force acting on it"), "definitory formula" (Braithwaite 1955) (such as W = mg), and characteristics (such as "weight is a vector").

Positivist philosophy recognized that the explanation of nature - unlike in mathematics - requires more than just theoretical definitions of the concepts involved. This development, which was apparent in Einstein's (1905) use of the concepts of time, simultaneity, and length, led to an appreciation of the fundamental role of the operational definition of physical concepts (Bridgman 1923/1964, p. 36). Thus, an operational definition defines the concept in terms of a particular measurement, indicating the apparatus and the conditions of measurement. Such a definition constitutes the concept's epistemic aspect:

> Ideally, each concept used in physical sciences can be made clear in terms of some such definition, and that is the mechanism whereby mutual understanding among scientists is made possible. For it is clearly more difficult to misinterpret action than words. (Holton 1985, p. 222)

Karplus (1981) claimed that operational definitions have a didactical advantage in that they are more accessible to students but warns about their weakness with regard to the structure of physics:

> The extensive use of operational definitions relates concepts directly to the students' experience and more-or-less familiar objects. Yet physics relationships among concepts must then be obtained from experiments that are carried out with the errors and uncertainties of such procedures, from teacher claims about such experiments that have been carried out by

> others (i.e., researchers in physics), or by means of theoretical derivations and "thought" experiments. (Karplus 1981, p. 240)

Note how in that claim Robert Karplus relates to science, science education research, science philosophy and, by referring to 'researchers in physics', also to the history of science. Hence, his approach was for us a way to interrelate all four disciplines.

However, Bunge realized that the operational definitions of physical concepts are not clear without any theory (Bunge 1963 pp. 60–61). Therefore, both theoretical (constitutional) and operational (epistemic) definitions should be employed in defining a given concept (Margenau 1950 pp. 220–244).

In the context of science education, the quality of definitions was regarded as an indicator of coherence (Bächtold & Guedj 2014; Galili and Lehavi 2006). Swartz (1999) drew attention to the many flaws in definitions, such as applying circular reasoning in connection with Newton's Second Law, found in textbooks of which teachers should be aware. Stinner (1992) and Hestenes (1998) stressed the essential contribution of definitions to the effectiveness of instruction. Operational definitions of physical concepts have been strongly advocated by several leading researchers in physics education (Arons 1965, 1999; McDermott 1996, 1997; Reif 1965). With regard to energy, providing a definition was found to be important in supporting teachers and increasing their confidence (Kruger 1990, Stylianidou and Ogborn 1999).

Teachers and textbooks were found to provide additional types of definitions to the theoretical and the operational (Galili and Lehavi 2006). Lexical (descriptive) definitions (Copi and Cohen 1990) were identified as a subcategory of the nominal definitions. Definitions in this subcategory describe concepts informally, as in a general dictionary, but not in a manner sufficient for a rigid discipline. The concepts were usually related to common experiences, sensations, or ideas and they used non-formal terms. For example, energy is often defined by relating it to fuel, sun's light, or electricity. The reliance on a descriptive rather than a quantitative approach might cause difficulties (Mclldowie 1995). Textbooks have rarely followed the advanced texts (e.g., Landau and Lifshits 1960) and they related energy to time symmetry and thus avoided its mere postulation. Such definitions were often far from accurate and never referred to measuring operations.

9.2.3.2 Addressing Experiment-Theory Relationships

The experiment-theory relationship is another strand of the philosophy of science discourse that can influence curriculum design, especially when considering whether to construct a concept's understanding deductively or inductively. With regard to energy, such a consideration can assist when one needs to decide how concrete (vs. abstract) energy should be presented in a curriculum.

According to the generative view (Koponen and Mäntylä 2006), adopting the epistemology of experiments requires an inductive justification of knowledge that can foster and guide students' own knowledge construction. It was claimed that the epistemological role of experiments in physics may help to reconstruct the use of experiments in their historical perspective. Thus, insights from history and philosophy of physics should be taken into account if one wishes to design an experimental-based curriculum and train teachers accordingly.

9.2.3.3 Implications for Energy Curriculum Design

Several approaches for addressing the challenge posed by the problems of defining energy have been suggested: (a) Avoiding a definition (Poincare 1903/1952, p. 167; Feynman 1964), (b) A mechanical definition as "the ability to do work", (c) A definition as "the cause of events" (Millar 2000), (d) A definition based on an operational definition of energy change (Karplus 1981),[6] and (e) Developing energy transfer and transformation as a theoretical framework that accounts for changes in very different systems (Bächtold and Guedj 2014; Papadouris et al. 2008).

It is apparent that in most cases if a definition of energy is provided, it would be formulated as a nominal theoretical definition rather than an operational one. The first two approaches seem to provide no or an incomplete answer to the question what is energy. The third definition, a causal definition of energy, as discussed by Ogborn (1986) and Millar (2000), is incorrect since it is entropy (or free energy), that can be said to 'make things happen'. The 'work' definition of energy could hinder our goal of unifying the concept of energy because it is hardly applicable for non-mechanical processes such as light absorption or chemical reactions. In fact, any mechanical-based definition of energy (e.g., through motion) will fail to unify such phenomena and therefore, it will be limited in rendering the idea of energy conservation plausible.

Consider, for example, using a pendulum in order to convey the energy conservation idea. Any classroom observation will demonstrate that the pendulum "loses height" as it swings until it stops its motion. This will happen even in vacuum. Therefore, if one relates energy to motion, the direct interpretation of observing the pendulum's motion will be that it lost its energy. In order to start looking for the "lost" energy, one assumes that energy is conserved and then one is also compelled to relate energy to phenomena other than motion. Hence energy dissipation and energy conservation are inseparable (Solomon 1982). However, following such an argumentation, students may find the unification of energy difficult and may view the structure of science as being based on cyclic reasoning.

Furthermore, the fact that students are very familiar with such non-mechanical processes stresses the didactic weakness of employing the mechanical definition.

Approaches (c) – (e) share in common the emphasis they put on processes and changes. The last two approaches, (d) & (e), seem to complement each other; however, they share an epistemic difference: (d) employs an operational definition of energy change, whereas (e) presents energy as an abstract, trans-phenomenological concept.

---

[6] Karplus suggested defining operationally the energy of a system *relative* to a system of ice and water at 0 °C as: "the mass of ice melted as the system comes to equilibrium with a mixture of ice and water". We consider this as a definition of the *change* in energy rather than the energy itself, since the result of such a measurement also depends on the relative motion and position of the measured system and the ice-water system.

Note that although energy does not lend itself to an operational definition (or, perhaps to any definition), a change in the energy of a system does. Therefore, keeping in mind Karplus'educational insights with regard to the advantage of using such definitions from the students' perspective, we decided to design the curriculum for middle school level around an operational definition of energy change.

Approaches (d) & (e) naturally directed us to follow Joule's approach and to establish a list of different processes (e.g., a change in height, a change in speed, and a chemical change) that share their capability to produce the same effect: changing the temperature of a certain object.[7] Choosing the temperature change of a standard object as our 'ruler' for measuring energy change, rather than some mechanical device, also enables, beyond the unification of the energy concept mentioned above, to avoid the difficulties posed by the 2nd law of thermodynamics, i.e., that a mechanical process can terminate with heating as the only final result but not vice versa (Arons 1999).

According to the operational approach, the teachers would have a valid rationale to *justify* the unification of the concept of energy change for cases where a change in temperature occurs:

Changes in characterizing variables (of certain processes) $\rightarrow \Delta T$ (of a standard object) $\equiv \Delta E$

The generalization to other processes is left for the next steps of the procedure. This approach enabled us to provide a definition of *energy change* as a quantification of processes:

> 'Energy change', corresponding to some process, is the maximal change in the temperature of a standard object that this process can induce.
>
> Or, less formally: 'Energy change' is the capability of a process to induce warming or cooling.

'Energy change' thus, provides a measure of the change in a system when it goes from one state to another through some process. The details of the process are not significant - only the difference between the different states. Note that the role of a system is greatly emphasized according to this approach. In addition, our definition enables to *quantify* energy change when a system undergoes a process and therefore, it differs from defining the energy of a system as its capacity to produce a change (Bächtold and Guedj 2014).

It should be clarified that the operational definition does not mean that the energy of a system does not change if there is no (or very little) change in temperature when a characterizing variable of a process changes. It only means that if one wishes to ascribe energy change to such a process, one has to refer to a measurement in which the change in temperature is the only change corresponding to the changing variable. Thus, if one wishes to analyze the swinging of a pendulum in terms of change in energy from the beginning of the swing to some intermediate position, one has first to ascribe independently, via measurement, energy change to the change in

[7] Karplus'suggestion has merit in that the change in the ice mass is the only change in an ice-water system, whereas using a thermometer also involves volume changes. However, carrying out a measurement such as that suggested by Karplus is not feasible in most classrooms.

height and the change in speed. One can then arrive empirically to the idea that the decrease in energy related to the decrease in height almost equals the increase in energy related to the increase in speed.

9.2.4 Science Education Research (SER): Studying Students' and Teachers' Pertinent Knowledge and Difficulties

Science education research provides information about students' and teachers' known pertinent knowledge and difficulties regarding various scientific concepts and ideas. Furthermore, analysis of textbooks can shed light on how a certain subject is planned to be presented and taught. The presentation can be categorized with respect to the different aspects of the concept on hand.[8] With regard to the special concept of energy, SER found that it presents a great challenge for teaching. The literature indicates that students lack a proper understanding of: (I) what energy is (its definition) and what is the meaning of: (II) energy forms, (III) energy transformation and transfer, and (IV) energy conservation (Duit 1984, 1985).

SER also indicates several additional challenges. Students have difficulties to relate quantitative and qualitative knowledge (Goldring and Osborne 1994) with regard to energy and difficulties related to the interrelation of work and energy and to the role of a system in this regard (Lindsey et al. 2009, 2012). The definition of energy seems to pose difficulties even to teachers (Trumper 1998, Galili and Lehavi 2006). In the past, many doubts were raised about the use of 'forms of energy' in teaching. Millar (2000, 2014) points out that very often energy forms serve as a list of labels to be remembered by pupils and that such forms add little, if at all, to explanations and understanding of phenomena. He further argues that energy forms may also complicate explanations by adding unnecessary variables and can even lead to incorrect analyses of processes. Most important to our approach, energy forms may hinder the importance of processes and weaken the unifying image of energy (Ellse 1988; Mak and Young 1987; Summers 1983).

Commonly, graduate-level physics textbooks define energy through a gradual construction: First, work is defined and then, when applied to various forces (e.g., gravitation or elastic), different expressions are obtained by defining the corresponding types of energy (Galili and Lehavi 2006). This method shows that many "types" of energy are based on the definition of work. However, this approach, as discussed above, may face difficulty in addressing heat or radiation. Hence, such phenomena are often postulated as additional options of energy transfer.

The concept of energy is rarely given a universal definition to which the learner can refer when considering something called "energy". Thus, energy cannot be well distinguished from other concepts (e.g., force) and is not sufficiently inclusive to account for its different "types". Therefore, the definitions of energy often lack the

[8] With regard to energy, see the comprehensive summary of Michelini and Stefanel (2010).

requirement of the scientific method, namely that a definition of a concept will differentiate it from other concepts and clarify its essence (Cohen and Nagel 1939, p. 232, 238). This, possibly, impedes a systematic exploration of the subject matter (e.g., the application of energy rather than force to chemical or biological systems).

Parallel to these deficiencies, there is a lack of consensus among physics educators as to the proper language by which energy should be described (Wolter and Martin 2002). In particular, the meaning of the above-mentioned four aspects is not agreed upon (Michelini and Stefanel 2014). For example, whereas energy is considered not to be a substance, the language used to describe some of its aspects (mainly energy transfer) may suggest a substance interpretation of energy.

Official international education standards and national curricula often leave much room for interpreting the meaning of the four aspects of energy. For example, the New Framework for K-12 Science Education uses terms like *energy generation* (e.g., pp. 9, 43), *energy flow*, and *energy transfer* (e.g., pp. 84, 89, 92, 93), energy storage (e.g., pp. 96, 121) without explicating their meaning (National Research Council 2012). Under the headline "What is energy?" the framework states: "That there is a single quantity called energy is due to the remarkable fact that a system's total energy is conserved". Such a statement clarifies the unitary aspect of energy but not the meaning of the concept (there are other conserved entities in science). The fact that various forms of energy still exist in the framework may also weaken the unitary statement. Energy as a quantitative property of a system is mentioned only once (p. 123) without specifying how its value can be determined. Moreover, scrutinizing the framework reveals that energy is predominantly mentioned with relation to its changes during processes due to transfer, interactions, and reactions, rather than its value within a system. This may provide a hint as to the importance of using energy changes rather than energy to describe and analyze processes and changes, as suggested by Hecht (2007).

The SER literature suggests that although forms of energy or its transformations do not have a solid scientific status, they are very useful in science teaching. Thus, in designing the curriculum we were challenged to develop teaching materials in order to address the students' difficulties and the teachers' need to possess a clear view regarding the meaning of the concepts they teach.[9] In designing these materials, we gave special attention to the unitary nature of energy and to the coherent meaning of such terms as energy "forms", "transfer", "transformation/conversion", and conservation.

In order to follow the goals of coherence and consistency, the curriculum design *required us to make didactical choices with regard to which definition to choose,* whether to focus on energy or on energy change to refer to energy forms or to avoid them, among other choices. We will demonstrate later possible ramifications of making different curricular choices with regard to the example of the energy change related to changes in speed ("kinetic" energy).

[9] It is not surprising that the Framework (pp. 95,96) calls for the need to have "a common use of language about energy and matter across the disciplines in science instruction" and that "the language of energy needs to be used with care so as not to further establish misconceptions".

Consequently, we had to make decisions concerning how to interweave the content and the means to support students in constructing their pertinent knowledge and understanding.

One can observe that many of the difficulties regarding the understanding of energy, as reported by SER, may be related to the "language of energy" as described above. These observations are summarized in the following table. We formulated the difficulties that were found to puzzle learners in terms of questions, and categorized them according to the corresponding energy curriculum challenges:

9.3 Teachers' Concept-Image of Energy

In parallel to our curriculum design, we conducted research on teachers' concept images of energy. It revealed that their concept image may pose a great challenge for curriculum design (Lehavi and Eylon 2014). We found that many teachers declared that energy is one entity, but, at the same time, many also did not agree with the statement that energy only changes in its value. Moreover, regarding energy transformations in general, the extent of agreement among the teachers regarding the unity of energy was considerably less. A similar picture of teachers' views was observed in their responses regarding specific cases of energy forms or types. There is an apparent gap between the teachers' statements regarding the unity of energy and their opinion regarding energy transformations and forms. This gap may indicate that the idea that energy is a unified concept is not fully accepted and is not clearly related to terms such as energy transformations and forms.

Most of the teachers indicated that the energy of an object is a relative quantity. However, their responses to questions that addressed specific cases revealed that many abandoned this idea in favor of the idea that energy is a property pertaining to a single object that is absolutely determined. This view ignores the systemic view of energy as is apparent in the case of an object's height energy, which disregards the Earth as a part of the system. In addition, most of the teachers hold the view that energy is contained within an object, which further weakens the relativistic view of energy. Only a few teachers agreed with the statement that a single procedure of measurement can be used to measure energy changes, and with regard to measuring energy itself, most of them did not respond. This may indicate that the teachers are confused with regard to the idea of unifying the concept of energy via measurement or they may even reject it. This, together with the confusion regarding the possibility of measuring energy changes by a single procedure, may have implications regarding the ability of many teachers to teach their students about the unification of energy.

With regard to energy conservation, our findings indicate that the energy conservation law (ECL) is perceived as an irrefutable law. This is supported by teachers' views of the limitations of measurement with regard to energy. Such a view of the conservation law assigns it a special status as a scientific law. Furthermore, the view that energy cannot be created or destroyed does not support the systemic view of the energy conservation law and might actually strengthen the material view of energy.

We found that the two aspects - energy conservation and energy transformations - nearly mirror each other in the teachers' views. Apparently, one is the reason for the other and, at the same time, its result. This view may suggest that some teachers regard ECL not as a basic law but as being derived from energy transformation. Such views possibly hinder a coherent justification of both energy transformation and the energy conservation law.

These findings may indicate the difficulties one may face in fostering a coherent teaching of the energy concept in such a way that energy forms (or types) together with energy transformation and transfer will be consistent with the unity of energy and its conservation (Eylon and Lehavi 2014).

9.4 Curriculum Design Decisions

Here we will depict the framework we employed in developing an 'energy change approach'. We will describe the points considered in this development and will provide specific examples from the curriculum.

It should be stressed that we focused on the teachers' concept image of energy. We therefore decided to support the unitary image of energy by regarding energy types/forms as *labels of different processes* in which the value of energy changes (i.e., increase or decrease) rather than perceiving the *existence* of different types of energies. The notion of energy increase/decrease assisted us in providing coherent meaning to confusing concepts such as energy transformations, energy transfer, and energy conservation. The finding that the teachers' declarative knowledge was not always in accordance with their deep-rooted beliefs and knowledge led us to construct ideas and activities that support their declarative knowledge. For example, the teachers' doubts regarding whether it is possible to construct an energy concept on the basis of experiments led us to generate simple and easy-to-use Joule-like experiments (Lehavi 2014; Lehavi et al. 2014a, b, 2016). Thus, we aimed at focusing the teachers' attention on the following observations:

9.4.1 Central Observations

As pointed out previously (Table 9.1), we opted in the energy curriculum to provide meaning to energy forms, transformations, conversions, transfer, and conservation. This required us to draw the students' attention throughout their learning to the following observations:

A. Co-variance of Changes An observation of various processes in nature revealed that they cannot be described by the change in one variable only. For example, when an object falls, its height decreases and its speed increases; when an object absorbs light there is less light and the object heats up.

Table 9.1 Energy teaching challenges and their relations to energy curriculum challenges[a, b]

Teaching challenges	Curriculum challenges
(a) Is energy a material entity?	**(I)** How can a definition be employed in order to provide meaning to energy?
(b) Is energy related to living things only?	
(c) Is energy a force?	
(d) How can we distinguish the energy scientific content from its everyday meaning?	
(e) What makes energy one concept and not many?	
(f) Is energy an absolute or relative entity?	
(g) Can we measure energy or is it only an abstract concept?	
(h) What does 'energy of an object' mean? (e.g., energy of a chocolate bar)?	
(i) How can we indicate the characteristics of energy (e.g., its conservation or relativeness) if we don't know what energy is?	
(j) Why does energy, unlike other physical concepts, have forms?	**(II)** What meaning can be ascribed to energy forms (types)?
(k) What makes these forms manifest the same entity?	
(l) How do we know that one or more forms of energy can be transformed into other forms?	**(III)** What meaning can be ascribed to energy transformations/conversions/transfer?
(m) Is energy transformation a consequence of energy conservation?	
(n) How do work and heat relate to energy change?	
(o) If energy is not a material entity, how can it move from one object to another?	
(p) How do we know that energy is conserved?	**(IV)** What meaning can be ascribed to energy conservation?
(q) Is energy conservation an empirical law of nature?	
(r) Can one, in principle, refute the energy conservation law?	
(s) Is energy conservation a consequence of energy transformation?	
(t) Does energy conservation mean that energy cannot be created or destroyed?	
(u) Does energy conservation mean that energy cannot be created or destroyed?	
(v) Why does energy conservation hold only for isolated systems?	
(w) If energy is conserved, what is the meaning of energy sources?	
(x) How can energy conservation be applied?	

[a]In some cases the difficulties from one category are closely related to those belonging to another category

[b]Most of these questions were the focus of the Discussion of Strand on Energy in Lower Secondary School, held at Girep 2010, Reims

This observation enabled us to relate to energy changes in simultaneous processes. Simultaneous changes can occur solely within a system or also in the system and in its surroundings. The simultaneity of changes enabled us to generalize the concept of energy change and to apply it to cases beyond those described by temperature change.

B. Opposite Arrows of Change A further observation revealed that simultaneous changes always occur in such a way that some of them correspond to an increase in energy and others to its decrease.

C. Simultaneous Changes in Energy Can Counterbalance Each Other The previously mentioned feature of opposite arrows of changes in nature does not necessarily imply that the corresponding changes in energy are mutually counterbalanced. This remains to be determined experimentally. One has to verify that for simultaneous changes to occur, the increase in energy corresponding to some changes equals the decrease in energy corresponding to the others.

D. Isolated Versus Non-isolated Systems The concept of simultaneous changes can be used to define operationally an isolated system:

> An isolated system is one that any change within it is not coupled by changes in its surroundings and vice versa.

Note that since the borders of a system are defined arbitrarily, one can transform a non-isolated system into an isolated one by expanding its borders.

E. Energy Conservation From observations A – D one can determine empirically that in an isolated system the energy increase corresponding to some processes of change is balanced by the energy decrease corresponding to other processes. Therefore, one can regard energy conservation as an empirical law that, in principle, is refutable.

9.4.2 Didactical Decisions

Considering the four disciplines as resources for guiding our curriculum design decisions led us to agree on the following didactical principles:

Focus on Observations To encourage students: to observe various processes and draw their attention to the changes involved in them without first using the concept of energy; to look for as many processes as they can that cause a thermometer to rise or fall in temperature; to look for a common feature that enables one to compare different processes[10]; to focus on energy increase or decrease as characterizing changes (processes) in nature rather than focusing on energy as characterizing static states.

---

[10] Some students say that time can be that common feature. A great idea!

Unification To unify the concept of energy change (its increase or decrease) by providing an operational definition based on Joule-like experiments, based on the change in temperature of a standard object.[11]

Reinterpretation To keep the traditional vocabulary owing to its convenience and frequent use, but suggest a new meaning to it:

– Energy transformations and transfer are presented as a convenient way to talk about energy increase and decrease in coupled processes and systems, respectively.
– Energy conservation is presented as an empirical observation of the balance between energy increase and energy decrease related to processes occurring in isolated systems.

Table 9.2 presents how our curricular decisions employed observations from Science, HS, PS, and SER:

9.4.3 Example: Different Definitions Imply Different Approaches to Teaching Energy Related to Motion

The following is an example of how one can adopt different definitions of energy change in order to arrive at the well-known expression for when an object stops:

$\Delta E_k \propto v^2–0$

A. A work-based definition:

(a) $\Delta E \equiv W \equiv F \bullet \Delta s = (ma) \bullet \Delta s = (m \dfrac{v^2 - 0^2}{2\Delta s}) \cdot \Delta s \propto v^2–0$

B. An operational definition:

(a) $\Delta E \equiv \Delta T$ (of a standard object) $\propto v^2–0$ (as measurements show)

Note that the first alternative requires knowledge of Newton's laws and kinematics in their mathematical formulation. Such sophistication is beyond the middle school level. The operational definition (alternative B), on the other hand, is based on knowledge of temperature measurement and the fact that a change in temperature, being a common result of different processes, can be agreed to define energy change. Such a view is well within the reach of our students, demonstrating rather well what Karplus'claim (p. 10) with regard to operational definitions.

[11] We used a simple kitchen thermometer that has a metal "sleeve" with the sensor inserted in it. The sleeve can be regarded as a standard object.

Table 9.2 Employing science, HPS, and SER in making curricular decisions

Alternatives	Observations from science, SER, and HPS	Our decisions
1. Which concept should be emphasized: Energy (static states) or energy change (processes)?	Scientists are mostly concerned with changes in the value of energy in different kinds of processes (the 1st law of thermodynamics) rather than in its absolute value, which is more ambiguous	To emphasize changes in the value of energy and hence, on the processes by which a system's state can change
2. Provide the emphasized concept with an abstract or a concrete definition?	Scientists and PS scholars regard operational definitions to be unambiguous. SER found that students and teachers have difficulties in understanding the abstract meaning of energy	To relate energy changes (increase or decrease) to a specific measurement: Temperature change of a standard object
3. Many "energies" (types/forms) or one?	Scientists regard energy as one concept. SER found that students have difficulties in accepting the unitary nature of energy and that the community of "experts" dealing with energy (teachers, engineers, and scientists) find the terms of energy forms to be useful.	To keep the terms of energy forms or types. To unify these terms through energy change by referring to a feature common to many kinds of processes: Their ability to warm or cool (a calorimetric approach following joule and Karplus). Thus, we defined energy change as a measure of the maximal ability of a process to induce change in the temperature of a standard object
4. Energy transfer interpretation: a substance "flow" or a change in the value of energy?	Scientists regard energy transfer as a systemic feature: Its increase or decrease owing to a system's interaction with another system (the 1st law of thermodynamics). SER found that students often regard energy as a kind of substance that can move from place to place	To relate to energy transfer in terms of a simultaneous decrease and increase of energy in interacting systems
5. Energy transformations: a change between different types/ forms of energy or a change in the value of energy?	Scientists did not reach a consensus regarding the scientific meaning of energy transformations. SER found that energy transformations, although useful for classroom discourse, strengthen the "many energies" concept	To relate to energy transformations in terms of a decrease and increase of energy in simultaneous processes
6. Energy conservation: a postulated character of energy or a systemic, empirically based law?	Scientists regard energy conservation either as coming from a general symmetry or as a systemic feature (through the 1st law of thermodynamics). SER found that teachers have difficulties in justifying energy conservation	To construct energy conservation as a systemic law representing the balance (supported by experiments) between the simultaneous increase and decrease of energy in certain systems

9.5 Implementation

The subject of energy is addressed directly in the Israeli middle school curriculum in grades 7 and 9. In addition, energy is addressed in grade 8 as part of a unit on electricity, and also in grade 9 as a part of a unit focusing on biology. At the middle school level the national curriculum addresses topics such as energy forms, energy transfer, energy transformations, and energy conservation and relates them to various phenomena. The main leap from the 7th grade level to the 9th grade level is that the latter requires introducing mathematical representation. Note that the Israeli national curriculum lets the textbook authors choose their own preferred didactics.

The curriculum resources that were designed according to the above approach were implemented in Israel in two phases: (a) Developing teaching materials for 7th and 9th grade science teachers[12]; (b) Developing textbooks for 7th and 9th grade levels. These phases were accompanied by special workshops for teachers.

In phase (a) the teachers were provided with a rationale explaining why energy is the "language of changes", followed by suggestions for classroom activities, such as simple experiments and demonstrations. The teaching materials also offered the teachers specially designed questions that emphasize changes rather than static states. For example, instead of asking what is the energy of a book standing on a shelf (given the book's mass and height above the floor), we asked what would be the change in energy when the book falls from that shelf to the floor; or, instead of asking what is the energy of a moving car (given its mass and speed relative to the road), we asked what would be the change in energy when the car stops. Similar questions were developed for other phenomena. The teaching materials that appeared during the years 2011–2012 interweaved teaching, learning, and assessment. The materials also offered a graphical representation that calls attention to processes in systems and the corresponding changes in energy (Fig. 9.1).

These materials are used by most of the science teachers in 7th to 9th grade. However, although mentioned in the rationale, these materials did not strictly follow the operational definition of energy change as mentioned above.

The materials for the 7th and 9th grades also added the operational definition of energy change by introducing the idea that many changes in nature can be quantified by measuring the change in the temperature of a standard object (a calorimetric approach).[13] Thus, these materials also offered Joule-like experiments such as those described previously (Lehavi 2014; Lehavi et al. 2014a, 2016).

In phase (b) the textbooks developed at the Weizmann Institute followed the approach described previously by referring *explicitly* to the students' (and teachers') attention to the following aspects of energy as a language of changes:

[12] These materials were developed, in addition to the authors of the current paper, by Rami Arieli, Amnon Hazan, Ayelet Weizman, Yael Bamberger, Tammy Yechieli, Oren Eckstein, and Roni Mualem.

[13] These units are not the only ones used in our system, which is in the middle of shifting from the old curriculum to the new one.

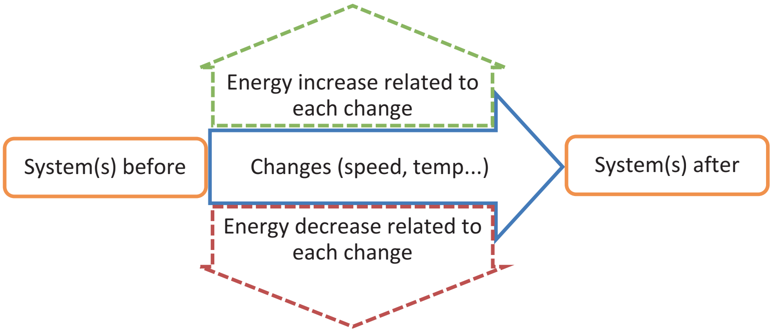


Fig. 9.1 Energy change diagram

1. *Processes:* Different processes in nature, characterized by changeable properties (parameters/indicators) such as height or speed, can be quantified by energy change.
2. *Simultaneous (or coupled) changes:* Changes in nature are always accompanied simultaneously by other changes.
3. *Unity:* Energy is considered to be a single quantity because its increase or decrease in different processes can be uniquely quantified via measurement. Different "types" or "forms" are only labels representing different processes in which energy increases or decreases (and thus they are not really different).
4. *Measurability:* Increases or decreases in energy can be verified experimentally. The results of such measurements can be generalized and used in mathematical expressions (for 9th grade level only).
5. *The meaning of "Energy transfer":* Simultaneous energy increase and decrease in interacting systems.
6. *The meaning of "Energy transformation":* An increase and decrease in energy in different kinds of simultaneous processes.
7. *Conservation:* The overall simultaneous changes in energy within certain systems (called isolated systems) are measured (or calculated, based on measurement generalizations) to mutually cancel out each other. In this respect, we wish to clarify that any classroom experiment can only support this idea as a plausible inference. We addressed it quantitatively in both grades (7th and 9th) with regard to the heat phenomenon by measuring the change in temperature of two identical objects having different temperatures. The students were able to observe that the decrease in energy of the hotter object equals the increase in energy of the colder one.

For the case of energy conservation during decreased height, we referred to it in the 9th grade as follows: First we established through Joule-like experiments that a linear relation between an energy change (measured by a change in temperature) and the height change is plausible. Then we did the same for the quadratic relations between the change in speed and in energy (again, measured by a change in temperature). We then demonstrated that for a falling body there is a linear relation between the decrease in the energy corresponding to the decrease in height and the

Table 9.3 The 7th grade unit components (14 lessons, 45 min each)

Subject	Key ideas
1. Energy – Phenomena & changes	Energy increase or decrease can describe different types of processes
	Each process can be characterized by some changeable property
	A change in temperature can indicate a change in energy
2. Energy conservation (an empirical approach)	A decrease in energy is always accompanied by its increase
	Observations and measurements show that in some systems energy increase is counterbalanced by energy decrease
3. Energy change	Energy transfer means the simultaneous energy increase/decrease in interacting systems, and energy transformation means the simultaneous energy increase/decrease in processes of different types
4. Where is the missing energy?	Changes in thermal energy cannot be fully reused
5. Energy change in warming and cooling	Heat is the gain in energy of a system due to its interaction with a warmer system
	Heat is related to radiation, convection, and conduction.
	Heat can indicate an open system

increase in energy corresponding to the increase in speed.[14] From these two experiments, together with all the qualitative examples of energy mutual increase/decrease, we were able to present the energy conservation as plausible inference.

We will describe here the structure of the 7th grade unit[15] developed at the Weizmann Institute: "A first Look at Energy", which was intended to lay the foundation for further development in the 8th and 9th grade units. The unit comprises five themes (Table 9.3).

9.6 Conclusion

We examined the importance of considering science, HS, PS, and SER when designing a coherent science curriculum for teaching energy and discussed in detail how they were used. SER provided answers to the question, what is required in the energy language in order to address the difficulties exhibited by students and teachers. Science provided us with the principles and laws that should be addressed, together with their interpretations. PS was examined in order to determine how to make scientific concepts meaningful and relate to the scientific structure regarding energy. HS gave us the means to justify scientific claims. In addition, the philosophical discourse regarding the experiment-theory relationship and the meaning of

[14] We analyzed a video of a falling object.

[15] Written by Amnon Hazan and Yael Bamberger, The Science Teaching Department at the Weizmann Institute of Science, Rehovot, Israel.

scientific concepts, with special attention to their definitions, provided essential and rich support in making curriculum and development decisions.

Note that each of the four PHES in our approach was employed not just for the sake of presenting them and discussing their role in understanding science, but rather, as a resource to be considered when designing a science curriculum. We regarded the PHES disciplines as important for providing guidelines for designing a curriculum rather than as bodies of knowledge from which the *content* of the curriculum should be enriched. This is especially salient with regard to the history of science. Although in our 9th grade textbook[16] we discuss the caloric theory as well as different alternatives to define weight, these are not considered by us as guidelines but rather as contents that we found important to be included in our textbook. In contrast, adopting operational definitions from PS (as well as from SER) and the Joule-Karplus thermal approach from HS, provided us with guidelines regardless of the important question of whether or not this choice should be presented explicitly to the students. Although the guidelines illustrate the approach to teaching energy, they can also be used for teaching other concepts such as electric charge or force. For example, our 8th grade unit on electricity relates the concept of electric charge to electroscope measurements and after discussing this topic, the different features of electric charge are studied.

We, as well as others (Eylon and Hofstein 2015), regard curriculum design as a discipline of its own that has undergone considerable changes in emphases and approaches. Like PS, HS the process of a curriculum design requires the examination of science in order to make it comprehensible. However, unlike those disciplines, the target population of the science curriculum designers is not the designers' community and its goal is not a scholarly investigation. Curriculum design is mainly concerned with making didactical choices with students' and teachers' communities in mind, along with practical ramifications. Therefore, it requires knowledge from the SER discipline.

It should be emphasized that we do not advocate only one way of using PHES in curriculum design. For example, one may wish to emphasize in a specific curriculum the evolution of science and hence, lean more heavily on HS or that part of PS that is devoted to the history of scientific discourse. In the case of energy, this would probably result in a curriculum much different from the one presented here – one that elaborates on how the concept of energy evolved in the course of scientific discourse. To cite another example, a curriculum that emphasizes contemporary science may highlight, as the New Framework for K-12 Science Education does, the role of fields with regard to energy. Nevertheless, we believe that in making any such curricular choices, the role of SER in the designing process should be central.

The idea that a curriculum design process should integrate multiple perspectives is not new. More than 40 years ago, Schwab (1973) argued that such a process should involve five commonplaces: subject matter, learners, milieus, teachers, and curriculum making. Our approach addresses all of these aspects, especially if one

[16]The 9th grade textbook was developed, in addition to the authors of the current paper, by Adi Rosen, Uri Ganiel, and Amnon Hazan.

accepts Null's (2011) interpretation of the subject matter as involving content and methods. However, since it is not clear in Schwab's framework whether and how considerations from PS and HS should be involved, we believe that our approach may complement this framework in curriculum design theory.

References

Adúriz-Bravo, A., & Izquierdo-Aymerich, M. (2005). Utilising the '3P-model' to characterise the discipline of didactics of science. *Science & Education, 14*(1), 29–41.

Angeles, P. A. (1981). *Dictionary of philosophy*. New York: Harper & Row.

Arons, A. B. (1965). *Development of concepts in physics*. Reading: Addison-Wesley.

Arons, A. B. (1999). Development of energy concepts in introductory physics courses. *American Journal of Physics, 67*, 1063–1067.

Bächtold, M., & Guedj, M. (2012). Towards a new strategy for teaching energy based on the history and philosophy of the concept of energy. In *Innovative methods for science education: History of science, ICT and inquiry based science teaching* (pp. 225–238). Berlin: Frank & Timme.

Bächtold, M., & Guedj, M. (2014). Teaching energy informed by the history and epistemology of the concept with implications for teacher education. In M. R. Matthews (Ed.), *International handbook of research in history, philosophy and science teaching* (pp. 211–243). Dordrecht: Springer.

Bevilacqua, F. (2014). Energy: Learning from the past. *Science & Education, 23*(6), 1231–1243.

Braithwaite, R. B. (1955). *Scientific explanations*. Cambridge: Cambridge University Press.

Bridgman, P. W. (1936). *The nature of physical theory*. New York: Dover Publications.

Bridgman, P. W. (1952). *The nature of some of physical concepts*. New York: Philosophical Library.

Bridgman, P. W. (1964). *The nature of a physical theory*. New York: Wiley.

Bunge, M. (1963). *The myth of simplicity*. Englewood Cliffs: Prentice-Hall.

Bunge, M. (2000). Energy: Between physics and metaphysics. *Science & Education, 9*(5), 459–463.

Chisholm, D. (1992). Some energetic thoughts. *Physics Education, 27*, 215–220.

Cohen, M. R., & Nagel, E. (1939). *An Introduction to logic and scientific method*. New York: Harcourt.

Coopersmith, J. (2015). *Energy, the subtle concept: The discovery of Feynman's blocks from Leibniz to Einstein* (Revised ed.). Oxford: Oxford University Press.

Copi, I. M., & Cohen, C. (1990). *Introduction to logic*. New York: Macmillan.

Duit, R. (1984). Learning the energy concept in school—Empirical results from the Philippines and West Germany. *Physics Education, 19*, 59–66.

Duit, R. (1985). In search of an energy concept. In *The paper was presented at the conference on: Teaching about energy within the secondary school science curriculum*. Leeds: The University of Leeds.

Duschl, R. (1985). Science education and philosophy of science, twenty-five years of mutually exclusive development. *School Science and Mathematics, 87*, 541–555.

Duschl, R. (1990). *Restructuring science education: The role of theories and their importance*. New York: Teachers' College Press.

Duschl, R. (2000). Making the nature of science explicit. In R. Millar, J. Leech, & J. Osborne (Eds.), *Improving science education: The contribution of research* (pp. 187–206). Philadelphia: Open University Press.

Einstein, A. (1905/1952). On the electrodynamics of moving bodies. In *His: The principle of relativity*. New York: Dover.

Elkana, Y. (2000). Science, philosophy of science and science teaching. *Science & Education, 9*, 463–485.

Ellse, M. (1988). Transferring, not transforming energy. *School Science Review, 69*, 427–437.

Eylon, B., & Hofstein, A. (2015). Curriculum development and change in the sciences. In R. Gunstone (Ed.), *Encyclopedia of science education* (pp. 258–264). Heidelberg: Springer.

Eylon, B-S., & Lehavi, Y. (2014). Position paper: Energy as the language of changes. In: Kaminski, W., & Michelini, M. (Eds.), *Proceedings of selected papers of the GIREP-ICPE-MPTL international conference, Reims 2010*, France (pp. 789–790). Università degli Studi di Udine, Italy.

Feigl, H., & Brodbeck, M. (1953). *Readings in the philosophy of science*. New York: Appleton-Century-Crofts.

Fermi, E. (1936). *Thermodynamics*. New York: Dover.

Feynman, R. (1964). *Feynman's lectures on physics* (Vol. I, pp. 4-1–4-8). Reading: Addison-Wesley.

Galili, I., & Lehavi, Y. (2006). Definitions of physical concepts: A study of physics teachers' knowledge and views. *International Journal of Science Education, 28*(5), 521–541.

Gilbert, J. K. (2006). *Science education: Science, education, and the formal curriculum* (Vol. 1). New York: Routledge.

Goldring, H., & Osborne, J. (1994). Students' difficulties with energy and related concepts. *Physics Education, 29*, 26–32.

Hecht, E. (2007). Energy and change. *The Physics Teacher, 45*(2), 88–92.

Hempel, C. G. (1966). *Philosophy of natural science*. Englewood: Prentice-hall.

Hempel, C. G. (1970). *Aspects of scientific explanations*. New York: Macmillan.

Hestenes, D. (1998). Who needs physics education research!? *American Journal of Physics, 66*, 465–467.

Holton, G. (1985). *Introduction to concepts and theories in physical science*. Princeton: Princeton University Press.

Karplus, R. (1981). Educational aspects of the structure of physics. *American Journal of Physics, 49*(3), 238–241.

Karplus, R., Pulos, S., & Stage, E. K. (1983). Early adolescents' proportional reasoning on 'rate' problems. *Educational studies in Mathematics, 14*(3), 219–233.

Koponen, I. T., & Mäntylä, T. (2006). Generative role of experiments in physics and in teaching physics: A suggestion for epistemological reconstruction. *Science & Education, 15*, 31–54.

Kruger, C. (1990). Some primary Teachers' ideas about energy. *Physics Education, 25*, 86–91.

Kuhn, T. S. (1962/1970). *The structure of scientific revolutions*. Chicago: University of Chicago Press.

Kuhn, T. S. (1977). *The essential tension: Selected studies in scientific tradition and change*. Chicago: University of Chicago Press.

Landau, L. D., & Lifshits, E. M. (1960). *Mechanics*. Oxford: Pergamon Press.

Lehavi, Y. (2014). Reproducing joule's experiment(s) in teaching the concept of energy. In Michelini, M. and Heron, P. (Organizers), Symposium: Teaching and learning the concept of energy from early childhood school through university. In Taşar, M. F. (Ed.) *Proceedings of the world conference on physics education 2012*, (pp. 491–498). Pegem Akademi, Istanbul, ISBN 978-605-364-658-7.

Lehavi, Y., & Eylon, B. S. (2014). Teachers' concept image of energy. In L. Dvořák & V. Koudelková (Eds.), *Proceedings of the international conference on physics education: Active learning – In a changing world of new technologies*. Prague: MATFYZPRESS publisher/Charles University in Prague. ISBN 978-80-7378-266-5. 492-500.

Lehavi, Y., Eylon, B. S., Hazan, A., Bamberger, Y., & Weizman, A. (2014a). Focusing on changes in teaching about energy. In M. F. Taşar (Ed.), *Proceedings of the world conference on physics education 2012*. Istanbul: Pegem Akademi. ISBN 978-605-364-658-7, 491-497.

Lehavi, Y., Eckstien, O., & Rosenzweig, G. (2014b). A simple kit for detecting quantitative changes in energy. In L. Dvořák & V. Koudelková (Eds.), *Proceedings of the international conference on physics education: Active learning – In a changing world of new technolo-*

gies (pp. 1219–1225). Prague: MATFYZPRESS publisher/Charles University in Prague. ISBN 978-80-7378-266-5.

Lehavi, Y., Amit Yosovich, A., & Barak, S. (2016). Bringing joule back to school. *School Science Review, 97*(361), 9–14.

Lindsey, B. A., Heron, P. R. L., & Shaffer, P. S. (2009). Student ability to apply the concepts of work and energy to extended systems. *American Journal of Physics, 77*(11), 999–1009.

Lindsey, B. A., Heron, P. R. L., & Shaffer, P. S. (2012). Student understanding of energy: Difficulties related to systems. *American Journal of Physics, 80*(2), 154–163.

Mak, S. Y., & Young, K. (1987). Misconceptions in the teaching of heat. *School Science Review, 68*, 464–470.

Margenau, H. (1950). *The nature of physical reality* (pp. 220–244). New York: McGraw-Hill.

Matthews, M. R. (2015). *Science teaching: The contribution of history and philosophy of science*. New York: Routledge.

Mclldowie, E. (1995). Energy transfer – Where did we go wrong? *Physics Education, 30*(4), 228–230.

Michelini, M., & Stefanel, A. (2014). Approaches and learning problems in energy teaching/learning: an overview. In: Kaminski, W., & Michelini, M. (Eds.*), Proceedings of selected papers of the GIREP-ICPE-MPTL International Conference , Reims 2010*, France, (pp. 779–788) Università degli Studi di Udine, Italy.

McDermott, L. C. (1997). Bridging the gap between teaching and Learning: The role of research. In E. F. Redish & J. S. Rigden (Eds.), *The changing role of physics departments in modern universities: Proceedings of ICUPE* (pp. 139–165). Woodbury: American Institute of Physics.

McDermott, L. C., & The Physics Education Group. (1996). *Physics by inquiry, Vol. I & II*. New York: Wiley.

Millar, R. (2000). Energy. In D. Sang (Ed.), *Teaching secondary physics* (pp. 1–43). London: John Murray.

Millar, R. (2014). Teaching about energy: From everyday to scientific understandings. *School Science Review, 96*(354), 45–50.

Monk, M., & Osborne, J. (1997). Placing the history and philosophy of science on the curriculum: A model for the development of pedagogy. *Science Education, 81*, 405–424.

Moore, G. S. M. (1993). General, restricted and misleading forms of the first law of thermodynamics. *Physics Education, 28*(4), 228–237.

National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. Committee on a conceptual framework for new K-12 science education standards. Board on Science Education, Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.

Null, W. (2011). *Curriculum: From theory to practice*. Lanham: Rowman & Littlefield Pub..

Ogborn, J. (1986). Energy and fuel: The meaning of the go of things. *School Science Review, 68*, 30–35.

Papadouris, N., Constantinou, P., & Theodora Kyratsi, T. (2008). Students' use of the energy model to account for changes in physical systems. *Journal of Research in Science Teaching, 45*(4), 444–469.

Poincare, H. (1905/1952). *Science and hypothesis*. New York: Dover.

Quinn, H. (2014). A physicist's musings on teaching about energy. In R. Chen, A. Eisenkraft, D. Fortus, J. Krajcik, J. Nordine, & A. Scheff (Eds.), *Teaching and learning of energy in K-12 education* (pp. 15–36). London: Springer.

Reif, F. (1965). *Fundamentals of statistical and thermal physics*. New York: McGraw-Hill.

Reif, Frederick. "Berkeley physics course." (1967).

Rudolph, J. L. (2000). Reconsidering the `nature of science' as a curriculum component. *Journal of Curriculum Studies, 32*(3), 403–419.

Schwab, J. J. (1964). Structure of the discipline: Meaning and significance. In G. W. Ford & L. Pugno (Eds.), *The structure of knowledge and the curriculum* (pp. 6–30). Chicago: Rand and McNally.

Schwab, J. J. (1973). The practical 3: Translation into curriculum. *The School Review, 81*(4), 501–522.

Shapin, S. (1992). Why the public ought to understand science-in-the-making. *Public Understanding of Science, 1*, 27–30.

Solomon, J. (1982). How children learn about energy—Or: Does the first law come first? *School Science Review, 63*, 415–422.

Stinner, A. (1992). Science textbooks and science teaching: From logic to evidence. *Science Education, 76*(1), 1–16.

Stylianidou, F., & Ogborn, J. (1999). Teaching about energy in secondary schools: The case of two innovations and Teachers' transformations of them. In M. Komorek, H. Behrendt, H. Dahncke, R. Duit, W. Gröber, & A. Kross (Eds.), *Proceedings of international conference*. Dordrecht: Kluwer.

Summers, M. K. (1983). Teaching heat - an analysis of misconceptions. *School Science Review, 64*, 670–676.

Swartz, C. (1999). Book report: Survey of high-school physics texts. *The Physics Teacher, 37*(5), 283–308.

Trumper, R. (1998). A longitudinal study of Israeli physics students' conceptions of energy in pre-service training for high school teachers. *Journal of Science Education and Technology, 7*, 311–318.

Tseitlin, M., & Galili, I. (2005). Physics teaching in the search for its self: From physics as a discipline to physics as a discipline-culture. *Science & Education, 14*(3–5), 235–261.

Wolter, H. K., & Martin, J. G. (2002). 'Forms of Energy', an intermediary language on the road to thermodynamics? Part I. *International Journal of Science Education, 24*(1), 81–95.

Chapter 10
Teaching Evolution: Criticism of Common Justifications and the Proposal of a More Warranted Set

Mike U. Smith

10.1 Introduction

Along with cell theory and the DNA theory of inheritance, evolution stands as one the three pillars of modern biology. It helps us understand phenomena in fields as diverse as genetics, anatomy, ecology, and physiology. Understanding evolution is important not just from a scientific perspective, but from a practical one as well. Evolutionary theory can help us solve real-world problems that have a biological basis — whether figuring out how to employ antibiotics more effectively or developing new pest-resistant crop varieties. These arguments have been widely used as justifications for evolution instruction. But, who is the "us" in the statement above? Does it include students? How do these justifications apply to the daily lives of students?

In an earlier paper (Smith 2010), I asked, "Why do students and members of the public at large need to understand evolution?" This question has also been asked in various forms by a few other researchers (e.g., Rosengren et al. 2012), but few have analyzed in detail the answers educators have been giving to these questions.

The universal response from biologists has been that public school students "need" to understand evolution. A wide variety of reasons for the inclusion of evolution has been proposed, but too often these justifications make sense to teachers and policy makers but do not appear to be convincing to introductory students.

This chapter will discuss the types of justifications that have been used to support science literacy in general and evolution understanding in particular. This chapter will also question the likely effectiveness of those reasons as justifications for teaching and learning about evolution. Recognizing the limited cogency of our student-centered justifications for evolution literacy, the preceding analysis also suggests

M.U. Smith (✉)
School of Medicine, Mercer University, Macon, GA, USA
e-mail: smith_mu@mercer.edu

M.R. Matthews (ed.), *History, Philosophy and Science Teaching*, Science: Philosophy, History and Education, DOI 10.1007/978-3-319-62616-1_10

that we need a discussion about how to make our justifications more relevant and convincing to students. The reader will likely be surprised with how limited our student-centered justifications for evolution literacy are. How can we make them stronger? Are there better justifications? A small set of justifications is proposed that might be more relevant, interesting, and convincing to young people, then I close with some educational implications of my position. This paper is meant to initiate a wider conversation among evolution educators about what student-centered justifications for evolution education there might be, including expansion and criticism of the list presented here.

10.2 Scientific Literacy and the Utility/Relevance Argument

Scientific literacy has long been a primary goal of science education. This prominence has resulted in such widely varying meanings for the term[1] that it has become impossibly vague and perhaps nothing more than an "educational slogan" (Roberts 1988; p. 28), a "myth," or "little more than a romantic idea, a dream that has little bearing on reality" (Shamos 1995; p. 215). Several worthwhile reviews of the topic have appeared in recent years.[2]

Science educators have grouped the proffered justifications for scientific literacy in various ways. One of the most widely cited of these schemes is based on Roberts' classification of the different "views" of science literacy: Vision I, focusing on the products and processes of science, (cf., the Project 2061 Atlas of Science Literacy—AAAS 1993, 2001; NRC 1995) and Vision 2, focusing on "situations with a scientific component, situations that students are likely to encounter as citizens" (Roberts 2007, p. 730).

Another useful categorization follows Roberts' (1988) earlier grouping of recommended science education curriculum "emphases": everyday coping, structure of science, science technology and decisions (about practical matters), scientific skill development, correct explanations, self as explainer, and science as a solid foundation.

Another grouping focused explicitly on science literacy justifications is presented in an earlier paper of mine: (a) utility, (b) democratic/civic/social, (c) economic, (d) cultural, (e) moral/ethical, (f) science career-related, and (g) aesthetic[3] (Smith 2010). In Roberts' (2007) terms, some of these justifications are more "student–centered" than others, and it is these that I assume will be most effective with students. The central questions are how well each of these types of justification measures up as being centered on students and how we can sharpen our arguments for encouraging student study.

[1] See DeBoer, (2000); Gormally et al. (2012); Millar (2005); Norris & Phillips (2003).

[2] DeBoer (2000), Hodson (2009), Laugksch (2000), and Roberts (2007).

[3] These categories are not meant to be non-overlapping.

The most common justifications for teaching science found throughout most organizational schemes fall in Roberts' Vision 2 (or "everyday coping") or the first two Smith (2010) groupings, focusing on utility/usefulness—especially utility "in daily life," or on creating "informed citizens," solving personally meaningful problems, shaping behavior, making important practical and political decisions, framing questions to science professionals, evaluating scientific claims, and engaging scientific information in the media.[4] This has also been called "civic efficacy or good citizenship" (Dewey 1916), "functional scientific literacy" (Aikenhead 2006; Jenkins 1990; Rennie 2007; Ryder 2001; Shamos 1995), "science education for action" (Jenkins 1994), "science for specific social purposes" (Layton et al. 1993), and "citizen science" (Irwin 1995).

Dewey (1916) characterized such aims as having "instrumental value," i.e., topics studied because of some end beyond themselves," not intrinsic value (p. 284). Science instruction that favors these aims might be expected to focus on practical applications such as the negative effects of the use of chemical fertilizers and pesticides, construction of nuclear power plants, use of ozone-destroying CFCs, climate change, the use of genetically modified organisms, etc. (Vilches and Gil-Pérez 2011; Osborne and Collins 2001). According to this view, if students take antibiotics in the future, they need to learn about evolution now to ensure that they do so properly. If students need to make sensible decisions about genetically modified organisms (GMOs), they will need to understand aspects of molecular genetics.

Two prominent criticisms of this "practical value" justification have been presented, even though they have mostly been ignored in the science education literature. First, Ryder (2001) has argued that the science topics we have chosen to teach because of their real-world utility have typically been selected on the basis of surveys of expert opinion (a top-down approach) instead of surveying members of the public or investigating situations where science is applied in real life (more bottom-up approaches). A prime, and often-cited, example of such a bottom-up approach is an analysis of 51 case studies to identify the science knowledge and processes people use to deal with various science related situations outside the classroom (e.g., options for incineration of local waste or dealing with the birth of a child with Down Syndrome) (Ryder 2001). Although this approach is clearly superior to top-down approaches, the underlying assumption in Ryder and similar studies is still that science is useful in everyday life. But what proportion of students is likely to deal with each of the issues so identified in order to make it worthwhile as a learning goal for all students?

The second criticism is found in more ethnographic studies of how individuals use science content and scientific skills in their daily lives outside the classroom.[5] These studies find that people rarely if ever use school science knowledge or approaches to make science-related decisions or solve science-related problems.

[4] Dempster and Hugo (2006), Feinstein (2010), Fensham (2002a, b), Gil-Pérez and Vilches (2005), Gordin (2015), Johnson et al. (2015), Kolstø (2001), and Lederman et al. (2012).

[5] E.g., Baram-Tsabari and Segev (2011), Basu and Calabrese-Barton (2007), and Feinstein (2010).

Thus, Ryder caricatured the utility justification as claiming that "thermodynamics is pressed into action to choose between one garment and another … polymer chemistry is used to decide what to spread on toast" (Ryder 1993; p. 148).

Another explanation of these ethnographic findings is, of course, that so much of the population is scientifically illiterate; they have very limited understanding of science upon which to base decisions about everyday science-related questions. An equally troubling explanation is that too many people hold the view that school science does not apply to their everyday lives (Aikenhead 2006; Feinstein 2009). Glen Aikenhead's extensive review of the relevant literature strongly suggests that:

> empirical evidence … contradicts scientists' and science teachers' hypothetical claims that science is directly applicable to a citizen's everyday life. … The fact is that this type of intellectual abstraction is relevant only to those who enjoy explaining everyday experiences this way. (Aikenhead 2006; p. 29)

Osborne maintains that today's science education is "not appropriate for the need of contemporary youth" because it is based on a group of "fallacies", one of which is:

> the fallacy that scientific knowledge has personal utility—that it is essential to the mastery of the technology; to remedy its defects; and to live as tease in the culture of technology that surrounds us. Yet as machines become more intelligent they require less care and thought for their effective use (Osborne 2007, pp. 174–175).

The utility argument is a bit like arguing that I need to understand how my carburetor works in order to drive my car – clearly this is not necessary. (See also Millar and Osborne 1998.)

Likewise, Jenkins (2003) has argued that "utilitarian claims for school science are naïve and misleading" (p. 10). Feinstein (2010) contends that, like literacy itself, usefulness "has largely been reduced to a rhetorical claim" (p. 168). Feinstein (2010) also argues that:

> decades of educational psychology tell us that this is a complicated and unlikely proposition. … It is a profound misconception that individuals make everyday decisions on the basis of formal principles and reliable knowledge built from the foundations up [because] … daily action and decision making rely on heuristic devices and tailored, situation-specific solutions (Feinstein 2010, p. 181).[6]

Dewey (1916) also argued that educators have focused too strongly on utility as a justification for selection of curricular content. "It is," he says "absurd to argue that unless teachers or pupils can point out some definite assignable future use to which it is to be put, it lacks justifying value" (p. 284).

Thus, in the most general terms, it appears that utilitarian justifications for developing science literacy are weak at best, although some have argued that this problem is the result of failures of science curriculum design focused on canonical principles (Aikenhead 2006; Feinstein 2009). Osborne and Collins (2001) join Aikenhead and Feinstein in arguing that the focus should instead be on topics more directly relevant to everyday life on and helping students learn to evaluate scientific

[6] Based, for example, on the work of Lave (1988), Layton et al. (1993), and Tversky and Kahneman (1974).

information—especially the trustworthiness of that information, becoming skilled consumers of science.

10.3 The Practical Utility Justification for Evolution Education

What justifications have been applied to *evolution* literacy *per se*, and in light of the criticisms just reviewed, how sound are these justifications? Surprisingly, only a small number of justifications for teaching evolution specifically have been put forward. As with justifications for scientific literacy, the majority of the reasons typically proposed for evolution education are utilitarian. Scientists and educators argue that knowledge of evolution is also "relevant to daily life," that it is "useful" or "valuable" for making sound decisions in the "real world" (e.g., Aikenhead 2006; Feinstein 2010). Utility is also the cornerstone of relatively recent arguments for the redesign of genetics instruction (Condit 2010).

One of the few explicit cases proposed as an example of the utilitarian value of evolution education is that of proper antibiotic use. Presumably, this justification is one reason why the development of antibiotic resistance is such a common instructional activity (Lead States 2013). According to this view, understanding (and acceptance) of evolution informs John and Mary Q Public's wise use of antibiotics, i.e., that if they understand how antibiotic resistance develops, they will be more likely to take the full course of antibiotics prescribed by their physicians. On the face of it, this claim seems logical, but two problems are apparent. First, this is an untested claim.

More importantly, there is an extensive research literature in health education that demonstrates that knowledge may be necessary but is clearly insufficient to determine behavior.[7] This research strongly suggests that knowledge of evolutionary mechanisms is unlikely to account for a substantial proportion of the variability in antibiotic-taking (or prescribing) behavior. We think that a host of other factors such as simple forgetfulness, attitudes toward authority, and cultural norms are likely to be more important. Thus, it seems that the most widely employed justification for evolution education has questionable merit.

The other commonly employed example used to buttress the practicality/utility justification for evolution education is that understanding evolution will help people make wise decisions about genetically modified organisms/foods (GMOs) (e.g., Lederman et al. 2012). GMOs have already become a major component of the world's foodstuffs—e.g., 91% of US soybeans (Anonymous 2014a), have the potential to reduce the use of pesticides and herbicides and the consequent pollution, and may make an important contribution to solving the persistent problem of world

[7] E.g., Atreja et al. (2005), Ferris et al. (2001), and Rogers (1983).

hunger, but people have raised many concerns about them as well. Consumer concerns are typically about food safety, risk to the environment, biodiversity and agriculture, and various issues of economic and governmental policy (Anonymous 2014b; Vilches and Gil-Pérez 2011).

Recent furor has arisen over the development of a variety of apple that lacks the enzyme that causes apple flesh to turn brown when cut. Responding to such concerns, many companies such as General Mills (maker of Cheerios®) have announced that their products will be GMO-free. Education about GMO-related issues is needed if modern society is to take advantage of potential benefits and prevent potential harm. The critical question for our discussion, however, is: How would evolution understanding facilitate consumer decision-making about GMOs?

First, it is demonstrably clear that evolutionary issues are central to the development and use of GMOs. For example, introducing genes into one species from another to produce combinations that have never existed before certainly raises issues about the evolutionary fitness of such hybrids - how the new cultivars would compete with existing varieties if the new ones were released into the environment. Again, these questions will be relevant to scientists, agricultural engineers, activists, etc. but to very few consumers.

Second, many people are concerned about the relative safety of consuming GMO foods. Does knowledge of evolution help consumers make decisions about consuming these foods? Safety decisions can certainly be informed by scientific knowledge about GMOs. For example, the fact that no scientific studies have identified any substantial difference in safety of GMO and non-GMO foodstuff consumption should be important knowledge for citizens as they make decisions about consuming GMO foods. If the utility argument for evolution education has merit, therefore, one might assume that the most knowledgeable individuals would be those most likely to be unconcerned about GMO foods. Again, a study testing this correlation has not been published to my knowledge, but anecdotal information suggests just the opposite conclusion. People most concerned about GMO consumption often seem to be very educated. In addition, the knowledge relevant to making these safety decisions lies primarily within genetics, digestion, and nutrition, not in evolution theory. How could understanding natural selection, genetic drift, speciation, or other evolutionary concepts inform GMO-related food safety decisions? No such informative pathways seem apparent.

Third, careful review of the GMO concerns of the public shows that the major concerns are about economics (“Big Pharma”) and ethics (Anonymous 2014b). As with the issues raised above, evolution understanding provides little or no guidance for addressing these concerns. Again, few of our graduates will be directly involved in these GMO-related discussions except through their representatives.

Second, and more generally, students can often see through our claims that evolution is of practical importance to their daily lives. They haven’t needed it before, and most don’t plan to become scientists or activists and so don’t see any need for it in the future. When students see through our claims, the teacher loses credibility and students find either limited or no reason for investing the effort required to understand evolution.

According to a largely ignored report from the United Kingdom (Millar and Osborne 1998), the familiar justifications for science education (and presumably for evolution education) "have been overused" and have "worn thin." If these are the strongest available examples of the value of evolution understanding in real world decision making, then either we should look for better examples or perhaps we must look beyond the practicality/utility arguments for justifying evolution education. How well then do the other justifications used for supporting science literacy identified above apply to students?

10.4 The Democracy Justification

Modern societies will indeed continue to make a host of decisions beyond antibiotic use and GMO consumption that should be informed by evolution. It will indeed be crucial for our representatives to understand evolutionary principles in order to understand the issues involved and make appropriate decisions. The evolution-related scientific ignorance of many American legislators—even of presidents and US representatives on the federal Science, Space, and Technology Committee—has been apparent in recent years (Nelson 2012).

Even more important than scientific ignorance is the fact that legislative decisions are often driven more by personal values than by science, whether learned at school or later as demonstrated by the refusal of the US Congress to fund needle exchange programs until 2009 even though clear data showed that such programs are effective in reducing HIV transmission (Office of National Drug Control Policy 2012).

But how does the need for educated legislators impact John and Mary Student? Few people in the modern world live in a true republic in which they have a direct voice in decisions, including decisions that may specifically require evolution understanding. People in democracies rarely have input into such specific decisions, except perhaps in occasional propositions or referenda or the occasional letter to a congressman. If they live in a democracy, John and Mary may at most be involved in selecting leaders who will make decisions about funding such endeavors, but how well do John and Mary, themselves, need to understand the principles of evolution in order to choose leaders wisely? Although a candidates' understanding of evolution may influence how some people will vote, it seems unlikely to be the deciding factor for many voters.

The argument is not that many of the justifications for evolution education used to date are incorrect or invalid or that they are not crucial at other levels and for other audiences such as policy makers. There is clearly great societal value in understanding evolution. Most of these justifications, however, are logically unsound or simply irrelevant and/or likely to be unconvincing to young people in our classrooms. They are instead convincing to *us* the converted educators.

Likewise, the argument assumes that evolution instruction can be an excellent vehicle for teaching about the nature of science, about judging the validity of claims from diverse sources, etc. But what is the value of understanding evolution itself? As Rosengren, Brem, Evans, and Sinatra put it,

> If we're going to ask people to expend the time and effort it requires to wrap their heads around a [sic] idea like biological evolution, it seems as though there ought to be a really big payoff for all that work (Rosengren et al. 2012, p. 1).

The analysis above suggests that the payoff may not be at the individual level. Should we then discard evolution instruction from all but pre-professional education programs and perhaps instruction for legislators? The argument below explains why the answer is still "No," although for reasons much less frequently cited.

10.5 Evolution Literacy Is an Essential Part of Scientific Literacy in Modern Society

Most of the types of scientific literacy justifications listed above can be called "macro" justifications, i.e., largely for the benefit of society. In contrast, "micro" justifications primarily affect the individual (Thomas and Durant 1987; Shortland 1988). Macro justifications are not student-centered and thus carry little or no sway with young people. For example, questions about the ethical implications of the conduct of scientific research or the moral implications of scientific advancement seem mostly irrelevant to students at this age, as does the need of a society to have high quality scientists or good decision-making citizens. Likewise, few young people care about how the economic health of a society depends on a scientifically-literate society. These criticisms are even more cogent for justifications of evolution literacy. What effective justifications, then, can be made for expecting students to develop evolution literacy?[8] What justifications will be motivating and convincing to our students?

Science literacy requires that evolution should be taught because:

1. it is crucial for future learning in biology—both inside and outside the classroom.
2. understanding evolution is widely recognized as a basic component of being a scientifically literate person.
3. it is inspiring and a thing of beauty that can enrich the lives of learners and help them understand living things, including themselves, and the interdependence of man and nature (Dewey 1916).

First are two micro utility arguments that have not been widely promoted: Students need to understand evolution as a foundation for understanding other parts

[8] The question of precisely what are the necessary and sufficient components of evolution literacy remains to be determined. A first approximation is the list of evolution-related content knowledge to be found in the various standards documents, but evolution literacy as described in this paper calls for much more—and, in terms of content, perhaps a good bit less.

of biology. As Dobzhansky said, "Nothing in biology makes sense except in the light of evolution" (1973). Pre-service science teachers in a recent study shared this view. They argued that evolution is "a huge part of understanding the rest of biology … it provides a foundation for the other units …. [which] kind of build off that" (Dotger et al. 2009; p. 563). These student comments reflect the *Next Generation Science Standards* (NGSS Lead States 2013) identification of the "Evidence of Common Ancestry and Diversity (LS4)."

Although the Dobzhansky claim has been oft-quoted and evolutionary concepts have long been a component of the biology curriculum, reasons for the importance of evolution have been claimed but rarely if ever analyzed. What specific examples can we propose in evidence of this claim? Certainly, we cannot understand the unity of all living things without understanding evolution. Without evolution we cannot explain why (almost) all living things have DNA as their genetic material, why the same histones form the chromosome scaffolding of so many diverse beings, why meiosis occurs in all sexually-reproducing organisms, etc. We cannot understand the advantages of sexual reproduction or how closely humans are related to chimps and apes.

Similarly, without evolution we cannot understand the diversity of living things. Why are there so many different species? Why is there so much variation within species? How does variation arise? How does each species come to be so well suited (adapted) to the environment of its specific niche? How do new species arise?

Likewise, at the organismal level, without understanding evolution, how can we explain the development over time of structures as complex as the flagellum or the human eye? At the cellular level, evolution helps to explain cell structure and specialization. At the sub-cellular level, evolution helps to explain the structure and function of organelles, proteins, and membranes and interactions between and among them. Moreover, given that many of our students will never take another biology course, understanding evolution is even more important if students are to become effective consumers of the scientific information they will encounter in the future.

Thus it appears that the justification for evolution education coincides with that of science literacy and biology education. If we value understanding biology for all students, then of necessity biology education must embrace evolution education.

Second, closely related to the justification above, because evolution is one of the "explanatory stories" discussed or alluded to widely in modern society, one can simply not be considered a "literate" or "educated" person unless one knows something about evolution. Educated people are expected to have an opinion on the subject, and education is greatly needed to inform those opinions. The twenty-first Century will truly be an information-rich world. Everyone will increasingly be bombarded with information, which not infrequently will require an understanding of evolution. Throughout their lives our students are likely to encounter allusions to evolution in many situations, including conversations, movies, the Internet, etc. If they know nothing about evolution, they cannot understand these media or engage in "reasoned discussions" about evolution-related issues (Lewis and Leach 2006). They cannot fully participate in modern society. This justification is clearly part and parcel of the arguments our society has long made for liberal education.

Dotger's pre-service science teachers shared this view as well. They argued that evolution is "necessary for modern general knowledge or to be an informed citizen" (Dotger et al. 2009; p. 562). To paraphrase Laugksch (2000), evolution "is as central to a truly cultivated mind as literature, music, and the performing arts" (p. 86) (see also Ryder 2002).

Finally, we have made far too little in the classroom of aesthetic justifications for scientific literacy in general and of evolution literacy in particular (DeBoer 2000; Dewey 1916; Feinstein 2010). Dobzhansky (1973) argued that "seen in the light of evolution, biology is, perhaps intellectually the most satisfying and inspiring science" (1973; p. 129). This claim has received far too little attention. Like so many stories in science, the story of Darwin and his journey toward the development of a solution for the ageless question of where we come from is fascinating. As an answer to a question that many students can identify with (where did we come from?), the modern evolutionary synthesis is a thing of beauty and elegance. Which one of us did not become a scientist/science educator because we were captivated by something we learned about science? For example, when we help students see the question, the conundrum to be solved, instead of only the answers as a "rhetoric of conclusions," they can see the beauty in both the process and the solution. Evolution "cuts straight to the heart of who we are, what our strengths and limitations are, and how they came to be" (Tatersall 2013). Understanding evolution is a way of "understanding ourselves" (Pigliucci 2005; p. 2).

For me, it was the first time I encountered Mendel and solved basic genetics problems. They were so beautiful! The logic was so simple! Many of my friends found the problems impossible, but the solutions were so transparent to me. They FIT! I was hooked. Yes, understanding science in general and evolution in particular can give pleasure, and enjoyment (Jenkins 2003; Carter 2008), "enrich" our lives (Anonymous 2014c), and lead to "personal self-fulfillment" (American Academy for the Advancement of Science 1990; Laugksch 2000). Consider:

> The scientist does not study nature because it is useful; he studies it because he delights in it and delights in it because it is beautiful. If nature were not beautiful, it would not be worth knowing, and if nature were not worth knowing, life would not be worth living. (Poincaré 1907; p. 8)

And:

> Knowing some things is a "part of being 'well-read' in science—an excellent thing indeed, and one capable of giving us joy and satisfaction, but not one that all of our students will find useful. (Feinstein 2010; p. 183)

10.6 Taking the Measure of the Foundational, Literacy, and Aesthetic Justifications

How well do these justifications fare against the criticisms lodged against those criticized above. How relevant are they to children's lives and how convincing are the arguments likely to be to young learners?

At the outset of this part of the discussion, I should acknowledge that, even in the sense I am promoting, most students will not *need* to understand evolution. They will rarely if ever need such understanding to make decisions in their daily lives. Just as with teaching algebra, history, etc., utility justifications are weak for these subjects and often a hard to "sell" to students. Justifying evolution literacy to young students is simply a tough job.

First, how much do students care about understanding evolution allusions in discussions at home, church, synagogue, or mosque or in information they encounter on the web, in blogs or tweets, on television and movies (think science fiction such as "Jurassic Park"), etc.? This justification has perhaps the greatest potential to encourage the study of evolution. Most of our students have already heard about evolution—some a great deal. They know that it can be a controversial topic and that many people hold very strong opinions about it. Controversies can be very motivating to secondary school students. Some students may already have formed opinions of their own and may strongly value understanding what biology has to say about those opinions. Many of the opinions held by young people are merely adopted from their parents, but a primary developmental task of teenagers is to question such views and decide for themselves. For these reasons some students can easily see the relevance of evolution learning as important to being wise consumers of information.

Second, it may be difficult to convince most students that evolution is fundamental to understanding biology and thus worthy of study because young people tend to focus on the present not the future. Teaching techniques that demonstrate the foundational nature of evolution are required if students are to be persuaded of this justification (see Implications section below).

Third, how interested are students in becoming literate/educated people? In becoming evolution literate? Some, though perhaps not enough, clearly are interested. They see the pitfalls and narrowed lives of the illiterate, and if learning about evolution is a part of literacy, they can see that such study is worthwhile—if only as a means to the end of getting a good job in the future. Public instruction in many countries has often done a poor job of convincing students of the value of such literacy, as evidenced by relatively poor performance on international exams such as the Program for International Student Assessment (PISA) exams (U.S. Department of Education, National Center for Education Statistics (2015). If we value evolution literacy so highly, however, educators must seriously consider how we can convince our students of its import.

Fourth, how much do students value the aesthetics of science and evolution? Few students will agree that they value beauty and wonder, but their behaviors often belie such protestations. Elementary education has long done the best job of tapping into this appreciation, e.g., watching caterpillars that spin cocoons and eventually become butterflies. Likewise, secondary biology education has paid at least lip service to aesthetics with pretty pictures in textbooks and beautiful videos and other materials in the resources affiliated with the text. And more could be done.

But what introductory biology and evolution education has largely failed to do is to invite students into the experience of the beauty of discovering a solution to a perplexing question, the joy of the "Aha!" moment, the beauty of how well evolutionary theory solves the quandary of where species come from, of mimicry, of the variety of breeds of dogs, of fossils and extinct species such as dinosaurs and mammoths. These topics are relevant to the interests of students. As many have noted, however, we have too often presented evolution (and biology and science) as a "rhetoric of conclusions" and not as a set of questions about the living world and how people have proposed and tested various answers to those questions. Evolution is a wonderful opportunity to learn about the questions people have asked and about how the answers to these questions have themselves evolved.

So, are these justifications for evolution literacy more relevant and interesting, more convincing for our students? I propose that they are—or at least they are potentially more relevant to students' lives than the arguments science educators and policy makers have been promoting (explicitly or implicitly). That judgment is, of course, left to the reader and to teachers and ultimately to the students themselves.

10.7 Current Practice, Implications, and Further Research

What justifications do teachers actually use in the classroom? To date, no published study has asked this question. In mock parent-teacher conferences conducted by American pre-service teachers, these soon-to-be teachers justified the teaching of evolution as a requirement of state or national standards, as necessitated in light of (US) court cases, or because evolution is included in the textbook (Dotger et al. 2009). The research design may have increased the defensiveness evident in this type of justification, but this study suggests that these justifications are used by some, perhaps many, teachers, at least in communities where evolution instruction is a volatile issue. Such justifications are indeed valid, and they may mollify angry parents. On the other hand, they are not student-centered and are not likely to encourage buy-in from young learners. As Dewey (1916) pointed out, these justifications likely "represent the values of adults rather than those of children and youth" (p. 283).

What then are the implications of adopting and promoting the positive justifications presented above for both what we teach and how we teach evolution? What suggestions can we make to both curriculum developers and classroom teachers?

First, a word of caution: Many of the activities for teaching evolution are "whiz-bang", "fun" activities. For example, many activities for teaching natural selection involve "selecting" buttons or paper dots against a colored or patterned background. Students often enjoy such activities greatly. Such activities present at least two problems. First, fun is not the same as relevant. We teachers see how the activity translates to an evolutionary principle, but in practice, students often get caught up in the activity itself and spend little time coming to understand what it means. Second, most students are at a concrete developmental stage in which understanding by metaphor is very challenging. It takes an excellent teacher to be able to help students translate colored dots of paper into abstract concepts such as changes in allele frequency due to differences in fitness. Put simply, teachers should be explicit about why students are doing what they are doing. They should focus students' attention on understanding the modeled process before, during, and after the activity and use real-world, familiar examples as well as models and metaphors whenever possible. For example, teachers might use the real-world studies of Peter and Rosemary Grant on the evolution of Darwin's finches on the Galapagos islands (Weiner 1994).

Second, many of the things we know about effective science teaching in general are even more important in evolution instruction. For example, students are more likely to invest themselves in learning when they see a purpose for the learning—when they need the understanding in order to answer a question or solve a problem that they are interested in. This approach has been called inquiry, problem-based, or case-based instruction, but it can also simply entail presenting questions and challenges that students, not the teacher, seek answers for. Likewise, instruction should be goal-driven; know specifically what you want students to achieve and aim learning activities toward that goal. If a primary goal is understanding the nature of science (NOS), evolution is a fertile ground for helping students understand when science does or does not apply to a question. Teachers should be explicit about this goal with their students, share their goal for each activity, model such decisions, give students practice, and provide coaching. (See, for example, Smith and Scharmann (2006) and Scharmann and Butler (2015)).

Third, this discussion raises the question of what the goals of evolution education should be. Justifications are easily translated into goals. I have therefore argued that the goals of evolution education should be understanding the basic concepts and how they underlie the study of living things, evolution literacy, and aesthetic appreciation. More generally, Feinstein (2010) has convincingly argued that the goal of science education (and I would argue of evolution education) is to help students become "competent outsiders" (p. 180). He argues that most people will always remain outsiders, rarely asking "How does science/evolution apply here?" The current system shortchanges the student by implicitly aiming to produce "marginal insiders" with little or no everyday competence. "It follows that the pursuit of science literacy is not incidentally but *fundamentally* about identifying relevance; learning to see how science is or could be significant to the things you [students] care about most" (Feinstein 2010; p. 180; emphasis in original).

Similarly, as with the research on NOS teaching, it seems wise to be explicit about the justifications for evolution education. At least some of the students sitting before you are likely asking themselves "Why do we need to learn this crap?" It behooves us as teachers to share our personal convictions about the value of this instruction. We need to design instruction to help students see evolution literacy as valuable to them personally. Sharing our justifications is a first step toward doing that. Another approach is a lesson that asks students themselves to generate justifications for learning about evolution (Scharmann 2005).

Fourth, if the goal is to build a foundational understanding of evolutionary principles, then not only is the focus on the principles, but also on the *foundational* nature of evolution (Jenkins 2003). This will require the oft-recommended use of evolution as the unifying theme throughout biology instruction. It means that evolution becomes the basic "explanatory story" for the whole of biology, a powerful "explanatory tool" for solving problems (Scharmann 2005; p. 13). Again, it seems especially important that teachers explicitly note that they are using this unified approach and that they frequently "step outside" the lesson content to note how valuable their earlier learning of evolution is to understanding the biological question being studied at the time.

Fifth, if the learning goal is evolution literacy, instruction could focus on its value and relevance. Teachers interested in relevance have long presented stories from newspapers and magazines and posted them on bulletin boards. They may also spend valuable class time discussing some of those stories or showing movies related to applications of evolution in daily life. These seem to be useful approaches for demonstrating the utility of evolution literacy for helping students become wise consumers of information. Today, of course, print newspapers and magazines have mostly disappeared from the homes of our students and movies have been replaced by videos. The primary source of information for today's students is likely the Internet, but the adept teacher can make similar use of websites, blogs, and games, which, in fact, can provide even more opportunities than print media. Students might, for example, engage in finding an answer to an evolution-related problem that arises in a news story, movie, or blog that is of interest to them (Evolution Today). Students then learn for themselves how necessary it is to identify personal misunderstandings/misconceptions, to understand certain evolutionary principles, to be adept at using evolutionary terms, etc. Such an activity might, for example, be based on the question: "Should we use antibacterial soap?" or "Should we use hand sanitizers frequently?" (Scharmann 2005). As Feinstein (2010) notes, "learning about science [evolution] in a deeply personal context could make students more willing to plunge into unfamiliar, science-tinged waters in the future" (p. 182).

Sixth, teachers can also focus more on the beauty and wonder to be found in the story of evolution and in how evolutionary theory answers so many biological questions. For example, the beauty of the Watson/Crick/Franklin model of DNA and the excitement of developing a model that would explain both the unity and diversity of living things can easily be found in reading Watson's (2001) account of the story, which might be assigned as outside reading with questions for thought and then discussion in class. Again, the teacher should point out how each learning experience is evidence for one of the stated justifications for understanding evolution.

Finally, recognizing that this instruction will require additional teaching, it is time that we reconsidered what is necessary for these future citizens to know, what skills they must have, and what attitudes they should hold. Perhaps, for example, it might not be necessary to spend so much time on mRNA translation, having students spend an entire lab hour using models to translate an mRNA model. Instead, we might present some dog skeletons and ask students: How did we get all these different breeds of dogs? Should they be called different species? Why/why not? How is what breeders do like what happens in nature? Then present a human skeleton and ask: What similarities and differences do you see? How does the theory of evolution explain these?

Adopting such an approach raises questions that call for further research. How do the three justifications proposed here speak to students; do they motivate learning of evolution? How can we best communicate these justifications to students?

Foundations: How can we design instruction that convinces students that understanding all of biology requires understanding evolution?

Literacy: What constitutes *evolution* literacy uniquely; what are the essential big ideas we can agree upon, etc.? What would effective instruction that promotes evolution literacy look like? Can we convince students to accept the importance of evolution literacy as a personal goal?

Aesthetics: How can teachers find the instructional time to address the aesthetics of evolution (and science in general)?

Utility: There is clearly a need for studies of the extent to which individuals can and do apply what they have learned in science class once they have graduated into the world outside the classroom (building on the work of people such as Basu and Calabrese-Barton (2007) in urban settings).

There is clearly a need for empirical studies testing the efficacy of instructional approaches that are built on each of these justifications.

In addition, what other justifications might be proposed that would be more productive? If utility is a poor justification, not just for evolution learning but for most of science learning, what would that mean for science instruction in general? For example, should we adopt the goal of producing "competent outsiders" instead of "marginal insiders" (Feinstein 2010). How would this impact the present overloaded, prescribed curriculum and high stakes testing?

10.8 Conclusion

So, do students need to understand evolution? Are there sound justifications for evolution instruction? Yes, but, as argued above, some commonly employed arguments are of questionable logical merit and others seem to be more relevant at a societal level. I maintain that efforts to convince students of the practical utility of evolution in their daily lives are often misguided. (I am not, however, arguing against the value of helping students see the relevance of evolution in the modern world in ways that impact their lives and their culture as a tool to motivate learning.)

I maintain that our purposes are better served by arguing that evolution is important (1) to becoming wise consumers of information, (2) to becoming literate individuals, and (3) to experiencing the beauty and wonder in the story of evolution and its power to explain living things.

Recognizing the limited cogency of our student-centered justifications for evolution literacy, the preceding analysis also suggests that we need a discussion about how to make our justifications more relevant and convincing to students. The reader will likely be surprised with how limited our student-centered justifications for evolution literacy are. How can we make them stronger? Are there better justifications?

Finally, this kind of instruction calls on all the skills of a master teacher and for them to play a somewhat different role. Motivating students to see the value of learning about topics like evolution that have limited relevance to daily life is indeed a challenge, especially given the student effort that may be required and not to mention the controversial nature of the subject itself in some settings. Also, taking the time to focus explicitly on justifications for evolution instruction will be a new role for many. Effective teachers may need to become, not just explainers, but advocates of evolution.

References

AAAS, American Association for the Advancement of Science. (1990). *Science for all Americans*. New York: Oxford University Press. Available at http://www.project2061.org/tools/sfaaol/sfaatoc.htm.

AAAS, American Association for the Advancement of Science (1993). Benchmarks for science literacy. New York: Oxford University Press. http://www.project2061.org/tools/benchol/bolframe.htm

AAAS, American Association for the Advancement of Science. (2001). *Atlas of science literacy*. Washington, DC: American Association for the Advancement of Science.

Aikenhead, A. (2006). *Science education for everyday life: Evidence-based practice*. New York: Teachers College Press.

Anonymous. (2014a). *About genetically engineered foods*. Center for food safety. http://www.centerforfoodsafety.org/issues/311/ge-foods/about-ge-foods#

Anonymous. (2014b). *Genetically modified food controversies*. Available at http://en.wikipedia.org/wiki/Genetically_modified_food_controversies. Accessed 20 Sept 2014.

Anonymous. (2014c). *Scientific literacy*. Available at http://en.wikipedia.org/wiki/Scientific_literacy. Accessed 22 Sept 2014.

Atreja, A., Bellam, N., & Levy, S. (2005). Strategies to enhance patient adherence: Making it simple. *Medscape General Medicine, 7*(1), 4.

Baram-Tsabari, A., & Segev, E. (2011). Exploring new web-based tools to identify public interest in science. *Public Understanding of Science Journal, 20*(1), 130–143.

Basu, S. J., & Calabrese-Barton, A. C. (2007). Developing a sustained interest in science among urban minority youth. *Journal of Research in Science Teaching, 44*(3), 466–489.

Carter, L. (2008). Globalization and science education: The implications of science in the new economy. *Journal of Research in Science Teaching, 45*(5), 617–633.

Condit, C. M. (2010). Public understandings of genetics and health. *Clinical Genetics, 77*(1), 1–9.

DeBoer, G. B. (2000). Scientific literacy: Another look at its historical and contemporary meanings and its relationship to science education reform. *Journal of Research in Science Teaching, 37*(6), 582–601.

Dempster, E. R., & Hugo, W. (2006). Introducing the concept of evolution into South African schools. *South African Journal of Science, 102*(3/4), 106–113.

Dewey, J. (1916). *An introduction to the philosophy of education*. New York: Macmillan.

Dobzhansky, T. (1973). Nothing in biology makes sense except in the light of evolution. *American Biology Teacher, 35*(3), 125–129.

Dotger, S., Dotger, B. H., & Tillotson, J. (2009). Examining how preservice science teachers navigate simulated parent-teacher conversations on evolution and intelligent design. *Science Education, 94*(3), 552–570.

Evolution Today. http://www.amnh.org/exhibitions/darwin/evolution-today/.

Feinstein, N. (2009). Prepared for what? Why teaching "Everyday Science" makes sense. *Phi Delta Kappan, 90*(10), 762.

Feinstein, N. (2010). Salvaging science literacy. *Science Education, 95*(1), 168–185.

Fensham, P. J. (2002a). Time to change drivers for scientific literacy. *Canadian Journal of Science, Mathematics and Technology Education, 2*(1), 9–24.

Fensham, P. J. (2002b). De nouveaux guides pour l'alphabétisation scientifique. *Canadian Journal of Science, Mathematics and Technology Education, 2*(2), 133–149.

Ferris, F. D., von Gunten, C. F., & Emanuel, L. L. (2001). Knowledge: Insufficient for change. *Journal of Palliative Medicine, 4*(2), 145–147.

Gil-Pérez, D., & Vilches, A. (2005). Contribution of science and technological education to citizens' culture. *Canadian Journal of Science, Mathematics and Technology Education, 5*(2), 253–263.

Gordin, M. D. (2015). That a clear line of demarcation has separated science from pseudoscience. In R. L. Numbers & K. Kampourakis (Eds.), *Newton's apple and other myths about science*. Cambridge, MA: Harvard University Press.

Gormally, C., Brickman, P., & Lutz, M. (2012). Developing a test of scientific literacy skills (TOSLS): Measuring undergraduates' evaluation of scientific information and arguments. *CBE Life Sciences Education, 11*, 364–377.

Hodson, D. (2009). *Toward scientific literacy: A teachers' guide to the history, philosophy, and sociology of science*. Rotterdam: Sense Publishers.

Irwin, A. (1995). *Citizen science: A study of people, expertise, and sustainable development*. New York: Routledge.

Jenkins, E. W. (1990). Scientific literacy and school science education. *School Science Review, 71*, 43–51.

Jenkins, E. J. (1994). Scientific literacy. In T. Husen & T. N. Postlethwait (Eds.), *The international encyclopedia of education* (Vol. 9, pp. 5345–5350). Oxford: Pergamon Press.

Jenkins, E. J. (2003). Postscript. In E. J. Jenkins (Ed.), *Innovations in science and technology education* (Vol. III). Madrid: UNESCO Publishing.

Johnson, K., Dempster, E., & Hugo, W. (2015). Exploring the recontextualisation of biology in the CAPS for life sciences. *Journal of Education, 60*, 101–121.

Kolstø, S. D. (2001). Scientific literacy for citizenship: Tools for dealing with the science dimension of controversial socioscientific issues. *Science Education, 85*(3), 291–310.

Laugksch, E. (2000). Scientific literacy: A conceptual overview. *Science Education, 84*(1), 71–94.

Lave, J. (1988). *Cognition in practice: Mind, mathematics and culture in everyday life*. New York: Cambridge University Press.

Layton, D., Jenkins, E., MacGill, S., & Davey, A. (1993). *Inarticulate science?* Nafferton: Studies in Science Education.

Lederman, N. G., Antink, A., & Bartos, S. (2012). Nature of science, scientific inquiry, and socio-scientific issues arising from genetics: A pathway to developing a scientifically literate citizenry. *Science & Education, 23*(2), 285–302.

Lewis, J., & Leach, J. (2006). Discussion of socio-scientific issues: The role of science knowledge. *International Journal of Science Education, 28*(11), 1267–1287.

Millar, R. (2005). Contextualized science courses: Where next? In D. Waddington & P. Nentwig (Eds.), *Making it relevant: Context based learning of science*. New York: Waxman Munster.
Millar, R., & Osborne, J. (1998). *Beyond 2000: Science education for the future*. London: King's College London.
Nelson, S. (2012). Anti-Evolution Rep. Broun wants to stay on science committee. *US News & World Report*. Available at http://www.usnews.com/news/articles/2012/12/03/anti-evolution-rep-broun-wants-to-stay-on-science-committee. Accessed 20 Sept 2014.
NGSS Lead States. (2013). *Next Generation Science Standards: For States, By State*s. Washington, DC: The National Academies Press. http://www.nextgenscience.org/. Accessed 13 May 2013.
Norris, S., & Phillips, L. (2003). How literacy in its fundamental sense is central to scientific literacy. *Science Education, 87*, 224–240.
NRC, National Research Council. (1995). *National Science Education Standards*. Washington, DC: National Academy Press.
Office of National Drug Control Policy. (2012). *Federal funding ban on needle exchange programs*. Available at http://www.whitehouse.gov/blog/2012/01/05/federal-funding-ban-needle-exchange-programs. Accessed 24 Sept 2015.
Osborne, J., & Collins, S. (2001). Pupils' view of the role and value of the science curriculum: A focus-group study. *International Journal of Science Education, 23*(5), 441–467.
Osborne, J. (2007). *Science Education for the Twenty First Century, 3*(3), 173–184.
Pigliucci, M. (2005). *Evolution's importance to society*. Available at: http://www.actionbioscience.org/evolution/pigliucci.html. Accessed 24 Sept 2015.
Poincare, H. (1907). *The value of science*. New York: The Science Press.
Rennie, L. J. (2007). What counts as science education? *Studies in Science Education, 43*, 135–143.
Roberts, D. A. (1988). What counts as science education? In P. J. Fensham (Ed.), *Development and dilemmas in science education* (pp. 27–54). New York: Falmer Press.
Roberts, D. A. (2007). Scientific literacy/science literacy. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of research on science teaching* (pp. 729–780). Mahwah: Lawrence Erlbaum Associates.
Rogers, E. M. (1983). *Diffusion of innovations*. New York: The Free Press.
Rosengren, K. S., Brem, S. K., Evans, E. M., & Sinatra, G. M. (2012). *Understanding evolution on Darwin Day*. http://blog.oup.com/2012/02/understanding-evolution. Accessed 18 Sept 2014.
Ryder, N. (1993). Vernacular science: Something to rely on in your actions? In P. J. Black & A. M. Lucas (Eds.), *Children's informal ideas about science* (pp. 148–171). New York: Routledge.
Ryder, J. (2001). Identifying science understanding for functional scientific literacy. *Studies in Science Education, 36*, 1–44.
Ryder, J. (2002). School science education for citizenship: Strategies for teaching about the epistemology of science. *Journal of Curriculum Studies, 34*, 637–658.
Scharmann, L. S. (2005). A proactive strategy for teaching evolution. *American Biology Teacher, 67*(1), 12–16.
Scharmann, L. S., & Butler, W. (2015). Two-year community: The use of journaling to assess student learning and acceptance of evolutionary science. *Journal of College Science Teaching, 45*(1), 11–16.
Shamos, M. (1995). *The myth of scientific literacy*. New Brunswick: Rutgers University Press.
Shortland, M. (1988). Advocating science: Literacy and public understanding. *Impact of Science on Society, 38*(4), 305–316.
Smith, M. U. (2010). Current status of research in teaching and learning evolution: II. Pedagogical issues. *Science & Education, 19*(6–8), 539–571.
Smith, M. U., & Scharmann, L. C. (2006). A multi-year program developing an explicit reflective pedagogy for teaching pre-service teachers the nature of science by Ostention. *Science & Education, 17*(1–2), 219–248.
Tatersall, I. (2013). *Why do we care about human evolution today?* Available at: https://www.bigquestionsonline.com/print/198. Accessed 24 Sept 2015.
Thomas, G., & Durant, J. (1987). Why should we promote the public understanding of science? In M. Shortland (Ed.), *Scientific literacy papers* (pp. 1–14). Oxford: Rewley House.

Tversky, A., & Kahneman, D. (1974). Judgment under uncertainty: Heuristics and biases. *Science, 185*(4157), 1124–1131.

U.S. Department of Education, National Center for Education Statistics. (2015). *The condition of education 2015* (NCES 2015–144), International Assessments. Available at https://nces.ed.gov/fastfacts/display.asp?id=1. Accessed 15 Mar 2016.

Vilches, A., & Gil-Pérez, D. (2011). Actual experiences and actions as essential component s of education for sustainability. *School Research, 74*, 59–71.

Watson, J. D. (2001). *The double helix: A personal account of the discovery of the structure of DNA*. New York: Touchstone.

Weiner, J. (1994). *The beak of the finch: A story of evolution in our time*. New York: Alfred A. Knopf.

Part IV
Indoctrination and Science Education

Chapter 11
Science Education, Indoctrination, and the Hidden Curriculum

Lena Hansson

11.1 Introduction

Are students indoctrinated in science class? What could that mean? If yes, what kind of views are teachers indoctrinating students into? Is it possible to avoid? Is indoctrination a useful concept when trying to understand what is happening in the science classroom? Such issues will be of focus in this chapter.

Historically there is no difference between the concept of indoctrination and the concept of teaching (Callan and Arena 2009; Gatchel 1972/2010; Green 1972). However, nowadays, indoctrination has negative connotations. It is not known exactly when this pejorative way to use the word began. However, Callan and Arena (2009, p. 120) provide an example from 1852 where indoctrination is positioned as something negative. However, different usage of the concept was used at the same time. Gatchel (1972/2010) writes that "little over half a century ago the employment of 'indoctrination' was no more offensive in educational circles than the use of 'education'. Indeed, the two terms were practically synonymous" (p. 9). Green (1972) adds to this by referring to the *Oxford English Dictionary* published around 1900 that did not distinguish indoctrination from teaching.

The definition of the concept of indoctrination, and how to distinguish it from teaching or from socialization, is discussed by philosophers of education.[1] The risk of indoctrination has been frequently discussed in relation to religious and political education, but less frequently in science education. When used in science education, it has been in relation to teaching controversial value-based areas (for example in environmental education), as well as in relation to teaching the nature of science and

[1] See for example Bailey (2010); Callan and Arena (2009); Snook (1972b/2010); Wilson (1964, 1972).

L. Hansson (✉)
School of Education, Kristianstad University, Kristianstad, Sweden
e-mail: lena.hansson@hkr.se

M.R. Matthews (ed.), *History, Philosophy and Science Teaching*, Science: Philosophy, History and Education, DOI 10.1007/978-3-319-62616-1_11

specific scientific models. It has also been used in more general discussions of whether teaching science should aim towards knowledge or belief.

This chapter will take as a starting point, discussions of indoctrination in philosophy of education. The value of philosophy of education for science education research is highlighted by Schulz (2014). He states that debates on the aims of education as well as the difference between education and indoctrination are important for science education research.

It is suggested in the literature that social and institutional structures should be taken into account when discussing indoctrination. In line with this Huttunen (2003) suggests that indoctrination can happen through the hidden curriculum (Snyder 1971). The chapter will discuss the possibility of using the concept of indoctrination in this way: in relation to explicit and implicit messages in science class that are part of the hidden curriculum. Focus will be on the part of the hidden curriculum that communicates views about science itself –specific "nature of science" perspectives as well as specific worldviews and ideologies communicated side by side with science content in the science classroom (without necessarily being part of the formal curriculum).

11.2 Indoctrination: The Concept

Indoctrination has long been a topic for analysis in the philosophy of education literature. Most teachers would feel attacked and offended if someone told them that they were indoctrinating students. Thus indoctrination has negative connotations for most people, including education scholars, teachers and the general public. The concept has generally come to mean the "unethical influencing in a teaching situation. Indoctrination means infiltrating (drilling, inculcating etc.) concepts, attitudes, beliefs and theories into a student's mind by passing her free and critical deliberation" (Huttunen 2003, p. 1). Indoctrination, in this way, is a "systematic distortion of some kind in the teachers' presentation of subject matter – a distortion that elicits, or could reasonably be expected to elicit, a corresponding distortion in the way students understand the subject matter" (Callan and Arena 2009, p. 105).

In line with this, in the general use of the concept, there is a stark dichotomy between objectivity and indoctrination (Stolzenberg 1993).[2] Thus, indoctrination nowadays is most often not viewed as something positive, but something that should be avoided. There are descriptions in the literature of how teachers navigate (and even exclude some aspects from their teaching) in fear of risking the indoctrination of students (Qablan et al. 2011).

However, even if indoctrination is most often viewed as negative and to be avoided, some scholars argue that avoidance is not always possible (Moore 1972).

[2] However, opposite to this there are also people for whom an "objective" teaching is part of the problem, e.g. not all parents want their children to rationally scrutinize everything (Stolzenberg 1993).

In addition, there are scholars who argue that indoctrination can sometimes be justified, for example, in the moral education of very young children, or depending on high values at stake. Discussions include, for example, whether it would be justifiable to indoctrinate students into democratic values (e.g. Kilpatrick 1972) or critical thinking (e.g. Cuypers and Haji 2006).

A need is identified in the literature to define the concept of indoctrination more stringently to be able to decide whether a teacher is correctly accused of indoctrinating. Snook (1972/2010) offers a philosophical analysis of the concept in an attempt to define it with the starting point of four different criteria: the *methods* of teaching, the *content* of the teaching, the *consequences* of teaching, and the *intentions* of the teacher. These criteria are widely used among philosophers of education who have discussed the concept of indoctrination and how to understand the difference between indoctrination and teaching. However, scholars do not always agree on which (or which combination of) criterion should be decisive.

There are scholars who argue for indoctrination being associated with specific *teaching methods* (e.g. Gatchel 1972/2010; Momanu 2012; Moore 1972/2010), for example, "the use of propaganda devices, including censorship" and "authoritarian methods" (Moore 1972/2010, pp. 93–94). Examples of authoritarian methods are when a teacher rewards the right answers and punishes with silence wrong answers, as well as not providing reasons for their claims (Bailey 2010, p. 276). Others argue that this criterion is not the most productive: "method is not a strong candidate as the criterion for indoctrination simply because it is extremely difficult to conceive of methods that are characteristic of indoctrination alone" (Bailey 2010, p. 276).

Also, *content* has been suggested as a possible decisive criterion. For example, there are arguments raised that only doctrines are possible to indoctrinate, or for defining a content based criterion in some other way (e.g. being about uncertain subject matters). Therefore, scholars arguing for the content criterion in different ways reason that there is a difference between consensus content and controversial content – where only controversial content could be subject for indoctrination. Flew (1972/2010) illustrates this by arguing for the difference between teaching controversial religious or political ideologies, and something like the multiplication tables. However, other scholars reject the notion of ideologies being the only content open for the possibility of indoctrination, for example, due to the difficulties with differing "between matters of broad consensus" and "contested claims" (Bailey 2010, p. 275). Green on the other hand, states that the difference between teaching and indoctrination "has nothing to do with the contents of beliefs" and refers that "two persons may hold to the same belief and yet one may do so evidentially and the other non-evidentially" (Green 1972, p. 33).

There are also scholars who discuss the *consequences* as a possible criterion for indoctrination. For example, Bailey (2010) discusses "closed-mindedness" (with reference to Laura (1983)) as a consequence of indoctrination while teaching is characterized by "open-mindedness". Focus, in this way to characterise indoctrination, is the care about "students' ability to judge for themselves" (Bailey 2010, p. 277), and about the autonomy of the student (Bailey 2010).

A well-discussed criterion in the literature is the *intention* criterion, which many scholars argue for as the decisive criterion (e.g. Snook 1972/2010; White 1972/2010). Wilson (1972) states that indoctrination is an "intentional activity: you cannot indoctrinate by accident" (p. 18). The indoctrinator must "intend his pupil to arrive at a certain belief" (p. 18–19). Also, when presenting the four possible criteria (see above), Snook concludes that the intention criterion is the most useful of them all. He states that "A person cannot indoctrinate if he is not doing anything intentional at all: one cannot indoctrinate by omission" (Snook 1972, p. 66). He further states:

> 'Indoctrination' implies a pejorative judgment on a teaching situation. It suggests that someone taking advantage of a privileged role to influence those under his charge in a manner which is likely to distort their ability to assess the evidence on its own merit. The positive intention to bring about this state of mind is sufficient for the application of the term to his teaching, even if he should fail in his task. (Snook 1972, p. 66)

Thus a teacher's intention is central for Snook and many other scholars. However this position has been criticised, with arguments that it is not necessary that the teacher *intend* the student to believe *non-rationally*. Wilson (1972) writes that even though indoctrination is an "intentional activity", it is possible that the indoctrinator (e.g. the teacher responsible for the indoctrination) "might say, and believe, that they were helping people to form their own beliefs rationally and freely, but this might not be" (Wilson 1972, p. 18–19). Wilson argues that the teacher must "intend his pupil to arrive at a certain belief" for being held responsible for indoctrination, but it is not necessary that the indoctrinator intends this to happen non-rationally, for example, due to the authority of the teacher (Wilson 1972, p. 18–19). Snook (1972) widens the meaning of intention when including what is "*foreseen"* by the teacher: "Such a desire is not necessary, however, if it is foreseen that this state of mind is likely as a result of what is being done" (Snook 1972, p. 66).

Snook's philosophical analysis has been a starting point for other scholars' reasoning on indoctrination and education, such as Peterson (2007) who criticises the definition using the "foreseen" because it "does not allow us to accurately identify indoctrination. We cannot know with any degree of certainty what another person desires or foresees". Due to this she suggests that we add *"the foreseeable"* to the concept of intent.[3] However, she also emphasises the importance that indoctrination is caused by the actions of the teacher: "We ought only to hold teachers accountable for indoctrination if it is foreseeable that students would hold beliefs in a non-rational manner as a result of their teacher's actions" (Peterson 2007, p. 303). Thus, if the relation between the teacher's actions and the fact that students have come to hold beliefs in a non-rational manner cannot be established, then the teacher should not be accused. In this way "intent" has been widened to include actions that are not necessarily a result of the teacher's desire to indoctrinate, but where this consequence was foreseeable. Such actions can sometimes be best understood by taking the institutional level into account. The suggestion of taking also the institutional level into account will be returned to later in the chapter.

[3] The foreseeable has been discussed also by Snook (1972/2010, pp. 156–157), who argued against it as a criterion.

11.3 Indoctrination and Science Education

As mentioned previously, indoctrination has often been discussed in relation to religious or political education. Religious sects as well as totalitarian states have been accused of indoctrinating young people. Some scholars argue that only doctrines are possible to indoctrinate (see above), whilst others such as Snook (1972) argue that in principle any content can be indoctrinated, while not all content is at all equally probable, since doctrines "often provide motive for indoctrination" (p. 67). Snook even uses "physics" as an example:

> Because we find it difficult to imagine a motive for indoctrinating physics we tend to exclude the teaching of such subjects from indoctrination. I have argued that the concept can include them, but a motive is needed to explain why anyone would want to indoctrinate them. (Snook 1972, p. 67)

However, there might be reasons as to way indoctrination could be relevant to discuss in relation to the teaching of science. There are even scholars who suggest that the risk of indoctrination is greater in subjects like science than in, for example, religious education due to epistemological assumptions often taken for granted in science (Leahy 1990). In this section the focus will be on how the concept of indoctrination has been used in relation to different practices of science education.

11.3.1 Indoctrination in Relation to the Teaching of Scientific Concepts and Models

Indoctrination has been discussed in relation to the teaching of scientific concepts and models, for example, when concepts and models are presented in the science classroom as "facts" without arguments. Mohanan states that in introductory textbooks one is likely to find statements such as:

> A dropped coin falls to the ground because of gravity.
> The Earth rotates around its axis.
> All matter is made up of molecules.
> There are two atoms of hydrogen and one of oxygen in a molecule of water.
> Oxygen has a valency of two, and carbon has a valency of four. (Mohanan 2000, p. 1)

These types of statements are also found in many science classes, where teachers present "facts" to students without describing the processes that have led to consensus on a specific model: "students are forced to accept a set of conclusions without knowledge of the reasons for believing them" (Mohanan 2000, p. 3). Using the content criterion, this would most probably not be viewed as an example of indoctrination – the content is scientific models on which there is consensus in the scientific community.

However, using the method criterion provides a different result. When presenting science in this way, the students' rationality is bypassed and the students are left to the authority of the teacher. Students who take the views described by the teacher to be their own will believe on non-rational grounds (the views have not been rationally evaluated by the student). The scientific models become something that many students believe in due to trust in the authority (the teacher), but not because of rational arguments (those they have not heard about). Thus, in such a case using a method or consequence criterion for indoctrination would position a teacher presenting science in this way as guilty of indoctrination.

Yet, if instead an intention criterion is used, then this point is not so straight forward. The teacher's intention is probably not to make students believe in a non-rational way, but this will be a consequence of teachers not problematizing this way to present science (a way that often is part of science teaching tradition). However, if we add not only what is foreseen by the teacher, but also what is foreseeable (Peterson 2007), then again the result will change: obviously it is foreseeable that some students will come to believe in a non-rational way as a result of the teaching. This use of the intention criterion (including the foreseeable) will position the teacher as an indoctrinator – the teacher could be informed of different possibilities for teaching the scientific model in focus and what these could result in. Being informed about such different possibilities includes understanding the differences between a teaching of "facts" without providing reasons, and a teaching that emphasizes reasons and describes the processes and discussions in the scientific community that have led to consensus concerning the scientific model in focus. However, it is not so sure that it really is foreseeable for most teachers, due to many teachers having limited nature of science training, and are part of an institution (school science) where the power of the science teaching traditions (including teaching "facts") is great. For the in-principle foreseeable to also be foreseen by the teacher, is often a big step.

Another related issue is the one of whether science teaching should aim at developing students' *knowledge* of science concepts and models, or whether it should actually aim at students *believing* in these models.[4] Traditionally, the learning of scientific concepts has been viewed in line with what is described in the 1982 article by Posner, Strike, Hewson and Gertzog: "Often … the students' current concepts are inadequate to allow him to grasp some new phenomenon successfully. Then the student must replace or reorganize his central concept" (Posner et al. 1982, p. 212). Although views concerning this have been developed further in different ways within the conceptual change paradigm (see Treagust and Duit 2008), these researchers do not discuss science learning in terms of the differences between knowledge and belief. Southerland and colleagues state that "often science education, especially conceptual change research, equates students' knowledge with students' beliefs" (Southerland et al. 2001, p. 342), and El-Hani and Mortimer state that with such an assumption of what learning science means it is "impossible to distinguish understanding from belief" (El-Hani and Mortimer 2007a, p. 672).

[4] See, for example, Cobern (2000b), Cobern (2004), El-Hani and Mortimer (2007a, b), Hoffman (2007), Smith and Siegel (2004), and Southerland et al. (2001).

However other scholars distinguish these concepts.[5] Cobern states that it is possible for a student to understand without taking the view to be her or his own: "…comprehension does not necessitate apprehension. One may well reject a concept that he or she fully comprehends while someone else apprehends it as knowledge" (Cobern 1996, p. 592). Science teaching that has changed beliefs as a goal for students is regarded by some scholars as risking indoctrination. Therefore, distinguishing between teaching for knowledge and for belief could be viewed as a way to avoid indoctrination. El-Hani and Mortimer write:

> students' understanding of scientific theories, models, and concepts is the proper goal of science education. We think that if science teaching adopts change of beliefs as a goal, it runs the risk of degenerating into nothing more than a proselytizing, indoctrinating, scientistic endeavor. The decision to believe or not in scientific ideas is up to the students, but they are necessarily entitled to understand those ideas, if they are to be successful science learners. (El-Hani and Mortimer 2007a p. 683–684)

Thus, teachers should not use their authority to impose specific beliefs upon students, even though from a science perspective there is consensus in the scientific community on the model taught. Instead the only aim should be understanding. Ultimately, this has to do with defending the autonomy (Bailey 2010) of the student: students should have the right to judge reasons and evidence, and themselves decide what they are to believe in. Aikenhead (1996) emphasizes that there are ethical as well as empirical reasons (the traditional approach has not succeeded for large groups of students) for adopting a "cross-cultural" learning approach in the teaching of science. For example, there are students who play "Fatima's rules" – that is they learn "without being intellectually engaged" (Aikenhead 2006, p. 28). Aikenhead describes how this is a strategy used by some students "who feel their teacher is attempting to assimilate them into the culture of science and who want to resist such indoctrination" (Aikenhead 2006, p. 28). In this way, indoctrination is discussed as a danger in respect of students who themselves have views and ways of reasoning founded in their own cultures, which differ (in different ways) from the culture of science.

This applies to both non-western and western countries since science also in western countries is a foreign culture for most students (Aikenhead 2006). For example, studies of students' worldviews[6] show that students frequently have worldviews that are more or less at odds with the ones most often taken for granted in science and in science class. Scholars, in line with this, discuss different approaches to avoid indoctrination by replacing the aim of believing/accepting with the aim of understanding (e.g. Southerland and Scharmann 2013).

Would it be correct to say that a teacher indoctrinates students when teaching with the aim set to change students' beliefs (not only aiming at understanding)?

---

[5] See, for example, Cobern (1991), Cobern (1996), Cobern (2004), Smith and Siegel (2004), and El-Hani and Mortimer (2007a, b).

[6] See, for example, Allen and Crowley (1998), Hansson (2014), Hansson and Redfors (2006, 2007a, b), Hansson and Lindahl (2010), Brandt (2007), Cobern (1993), Cobern (2000a), Cobern et al. (1999), and Lee et al. (2012).

Again, this depends on the criterion used. When aiming to change belief one could argue that most teachers do not intend this to happen non-rationally. When using the concept in the way suggested by Snook (1972), this is not a case of indoctrination because the intent is not there. However for Wilson it is considered enough that the teacher "intend[s] his pupil to arrive at a certain belief", but it is not necessary that the teacher intends this to happen non-rationally (Wilson 1972, pp. 18–19). Using this definition, the teacher could be held guilty of indoctrination. Also, when arguing along the lines of Peterson's (2007) reasoning (including the foreseeable), the teacher would be an indoctrinator in this case. This is due to the fact that it is foreseeable that a teaching for change of belief runs the risk of indoctrination – at least in cases when focus is not put on arguments and reasons, but instead on the change of belief as such.

Indoctrination is foreseeable because research shows that not all students accepting a scientific model do this on rational grounds, but simply adopt a teacher's beliefs. For example, Sinatra et al. (2003) show that there are students accepting the theory of evolution without understanding what the theory really means or its supporting evidence. Here the content is not of concern, but instead that the teaching has by-passed students' rational evaluation. In these types of cases it can be argued that the teacher takes "advantage of a privileged role to influence those under his charge in a manner which is likely to distort their ability to assess the evidence on its own merit" (Snook 1972, p. 66). Much science teaching, from the above perspective, could be viewed as guilty of indoctrination when students, as a result of teaching, come to accept a specific model as true without knowing why; or when teachers use their power to convince students to change their beliefs.

However, it should be noted that there are also many students for whom attempts at indoctrination are unsuccessful. Instead, many students play "Fatima's rules" – e.g. learning statements or procedures by heart without engaging intellectually, or find different kinds of "cross-cultural" (Aikenhead 1996, 2006) strategies where they separate their knowledge of the scientific view and their own views. For example, colleagues and I have shown in previous research that students frequently associate one view with science, but state that they themselves view the same thing in a different way (Hansson and Redfors 2006; Hansson and Redfors 2013). In these cases, students have resisted indoctrination in respect of them not adopting the taught views. However, it is possible to argue that students in some of these (and other) cases are *indoctrinated into associating specific views with science*. Without really knowing why a specific view is the view of science, this is associating science with these views on non-rational grounds (without any rational evaluations), which could be considered as a possible example of indoctrination.

We have seen that teaching models as facts, and teaching for belief (not only knowledge), have been discussed as indoctrination in the literature. However, the kind of criterion that is used for indoctrination in science education literature is often only implicitly communicated. Thus, whether the discussed cases should be judged as indoctrination depends on the criterion used: for example, according to the method and consequence criteria it is indoctrination, while it is most often not if viewed against a content criterion. As seen above, scholars have frequently argued for the importance of the intentions of the teacher. In the cases described here it is unclear whether the indicator of indoctrination is really the intent of the teacher. The question then arises: can it, nevertheless, be fair to talk about indoctrination? Later in this chapter it will be argued that the institutional level should also be taken into account.

11.3.2 Indoctrination in Relation to Controversial, Value Based Issues

When the concept of indoctrination occurs in science education it is often invoked concerning controversial and value based areas such as environmental issues (Poole 1995). Also, in general philosophy of education, the treatment of controversial issues in school is discussed in relation to indoctrination (Kilpatrick 1972).

Indoctrination is discussed in environmental education, and education for sustainable development.[7] For example, in a case study of professors in environmental science (Qablan et al. 2011) it is shown how these professors, due to the fear of indoctrinating students ("My job isn't to tell them what to think"), emphasize the scientific part of curricula in Education for Sustainable Development (ESD) courses. They teach what they view as objective (scientific) facts. The professors feel that they run the risk of communicating biased ideas to students if they deal with economic or social dimensions in combination with the scientific dimension of ESD (Qablan et al. 2011). Öhman (2007) describes three selective traditions in Swedish environmental education. One of them is the fact-based tradition (the one used by the professors in Qablan et al. (2011) described above).

Other traditions are the normative tradition and the pluralistic tradition. The criticism of the normative tradition is in line with the fear of the professors in the study by Qablan et al. (2011): "there is a danger that education will lose its emancipatory potential and its democratic obligation will be violated; the result being that education then resembles indoctrination" (Öhman 2007, p. 44). The third tradition (pluralistic) attempts to avoid indoctrination by promoting critical thinking and discussing different viewpoints. On the other hand, this instead runs the risk of open up for relativism – students could for example be given the impression that there are two serious sides to the issue of global warming.[8]

Also concerning other controversial issues (e.g. "socio-scientific issues", SSI) there could be a fear of biased presentations (Couló 2014) and of indoctrination (Pedretti et al. 2008). This is especially the case when teaching for change of the present state in society (Bobel 2006). In such cases the teaching is connected to

[7] See, for example, Jickling (2003), Qablan et al. (2011), Qablan et al. (2009), Tabone (2011), and Östman (2010).

[8] Some, for example, Öhman (2007), argue against pluralistic ESD being necessarily relativistic.

activism (Bencze and Alsop 2014) in some way, and becomes openly political and ideological. In such cases the teacher runs the risk of ending up being accused of indoctrinating students (see the examples above concerning environmental issues). However not mentioning societal aspects of different kinds, of relevance for the science taught, could be seen as problematic. It could be argued that it is the responsibility of the teacher to tell students about different viewpoints concerning controversial issues. Not doing so makes action impossible for the students and the teacher could instead be accused of indoctrinating students into the present dominating ideological viewpoint. For example, a number of scholars state that some ideological perspectives (e.g. neoliberalism and modernism) are more frequently communicated in the science classroom than other ideological perspectives.

For example, Bencze and Carter (2011) discuss science education in relation to neo-liberal agendas, and Selby (2014) states that science teaching tends to communicate views such as “unending economic growth”, “ever upward progress” and “technological fix”, as well as the dominance of humans over nature (Selby 2014, p. 172). A concrete example of how these types of ideological perspectives are communicated in the science classroom is presented by Solli et al. (2014), who show how a professor during an introductory course in biotechnology “was engaged in convincing the students into being critical towards opposition to GM food” (Solli et al. 2014, p. 19).

Different approaches have been put forward concerning how to deal with controversial issues in educational contexts (Ashton and Watson 1998; Reiss 1993). The problem here is the same in all education (and not specific for science education). It is about whether the teacher should try to be neutral (in some way) or whether the teacher should tell students about her or his own viewpoint. Telling students about their own view runs the risk of being accused of trying to indoctrinate them. On the other hand, it could be argued that teaching cannot be value-free, and telling students about the teachers’ own view and having this view scrutinized with other views is the best thing to do (Ashton and Watson 1998). Hodson (2014) discusses the problems with a so called “balanced view” – “*all* views embody a particular position, and that position needs to be rationalised and justified if indoctrination is to be avoided … I believe that students have a right to know their teacher’s views on SSI addressed in the curriculum” (Hodson 2014, p. 74).

11.3.3 Indoctrination in Relation to Teaching of the Nature of Science

In relation to teaching the nature of science, concern has been raised due to the risk of indoctrinating students. Matthews (1998) states:

> there is a danger that teachers, curriculum developers, and examiners will define ‘epistemological development’ merely as ‘believing what I believe about epistemology’. When this happens, we confuse education with indoctrination. (Matthews 1998, p. 167)

In such cases the purpose of teaching nature of science is to convey to students a "particular view about the nature of science" (Matthews 1998, p. 167). That could be "constructivist/positivist/realist/feminist/Marxist/multiculturalist/universalist views about the nature of science" (Matthews 1998, p. 167), or something else.

In the case described above the teacher explicitly teaches a specific nature of science perspective (controversial content) with the intention that students should adopt the same view without necessarily scrutinizing different alternatives. If using the content criterion one could argue that this is a clear case of indoctrination, and in this case also the intention criterion is fulfilled.

There is also the problem of science teaching frequently conveying stereotypical and mythical images of science to students, for example that scientists always follow one specific "scientific method", that creativity is absent from the research process and that scientific research is entirely objective and universal and produces objective, absolute knowledge (facts) about the world (McComas 1998). There is a large amount of research showing how teachers communicate such stereotypical images of science in their classrooms even though they do not intend to teach nature of science at all (Abd-El-Khalick 2012; Clough 2006). Such views are conveyed anyway, implicitly, through lab work that strengthens the notion of *one* scientific method/procedure, or through the way the teacher implicitly presents a model as an unchangeable fact. Teachers are not alone communicating these kinds of images of science. Medawar (1961/1996) argues that scientific research articles also do "give a totally misleading narrative of the processes of thought that go into the making of scientific discoveries" (p.38).

Related to this are examples of scholars discussing indoctrination in relation to worldview. Van Eijck and Roth (2011) state: "Teaching science is a double-edged sword, because students … may actually be indoctrinated into a particular worldview consistent with classical metaphysics (Western science) rather than learning to critically reflect the value of different knowledge systems." (van Eijck and Roth 2011, p. 832). In line with this, Proper and colleagues (1988) show that only a few worldviews are communicated in the teaching of science, and most often implicitly. Taber (2013) states: "there is much potential for the image of science offered to pupils to be scientistic" (Taber 2013, p. 153). In line with this I and colleagues (Hansson and Redfors 2007a,b; Hansson and Lindahl 2010, 2015) show how students in fact often associate scientism with science and this is discussed as an indoctrination of students into associating such kinds of views with science (Hansson and Lindahl 2015).[9]

In the same way as teachers can become guilty of indoctrinating students with specific nature of science perspectives, there is also a communication of nature of

[9] Scientism can be defined in different ways (Stenmark 2001). Here a definition is followed suggested by Poole (1998). Poole argues that scientism, but not science, "Denies that anything other than the natural world exists", states that "Scientific accounts are all there are", "Denies that there are *first* causes or *final* causes", and "Denies that there could ever be behavior other than law like (anti-miraculous)" (Poole 1998). When such views are claimed "in the name of science" (Stenmark 2001), this is what is meant by scientism in this chapter.

science in science textbooks (DiGiuseppe 2014) that could contribute to indoctrination. For example, in a study of science textbooks Knain (2001) shows that the image of science communicated is:

> [one] where individual scientists are discovering truth, through experiment. Scientific rationality is grounded in procedures of inquiry alone and not in debate and argumentation within scientific communities. The communal aspects of science tend to become visible in historical examples where science did not function properly due to prejudices or ignorance. (Knain 2001, p. 319)

There is not one nature of science (Alters 1997). When teachers intentionally argue for a specific perspective (as discussed in the quote by Matthews above) on such a controversial issue then this is a self-evident case of indoctrination (e.g. using the content or intention criterion). Also, when teachers are not arguing for, but take specific perspectives for granted, this could be viewed as indoctrination, if using for example the content or consequence criterion. Cobern (2000b) states that the teacher who takes presuppositions for granted, which are not necessary for science, distorts science for the students. This is what has happened when students have come to associate science with for example scientism and atheism (Hansson and Redfors 2007a, b; Hansson and Lindahl 2010). However, it is uncertain if these cases could be judged as indoctrination if the latter is defined in terms of the intention criterion.

Also, the presuppositions necessary for science (which science builds upon) and that are taken for granted in science class, can be seen as part of the indoctrination of students. Leahy (1990), building upon Laura (1983), argues that any belief system depends on assumptions ("epistemic primitives") about the world. This is also in line with the worldview theory building on Kearney (1984) and applied in the science education context by Cobern (1991). Leahy argues:

> If student access to truth is to be properly safeguarded … students will need to be provided … not only with an understanding of the content of the subject concerned, but also of the 'epistemic primitives' underpinning that subject. To teach the content of any subject without also providing students with an understanding of that content's dependence on its 'epistemic primitives' would be to indoctrinate rather than to educate. (Leahy 1990, p. 142)

An example of this is students who do not know that science presupposes that the universe is ordered and uniform. For these students, it is not possible to in a meaningful and rational way understand for example conclusions drawn about the abundances of elements in stars from observed spectra (Hansson 2014). This is but one example of how students' knowledge about the presuppositions of science can interact with their understanding of scientific models (for a more in-depth discussion about this, see Hansson 2014). Leahy points to that by looking at indoctrination in this way there is a "danger of indoctrination in all subjects" (Leahy 1990, p. 142).

We have here encountered examples of how indoctrination can be discussed in relation to teaching of the nature of science. However, teachers are not always aware of what they are doing. Perhaps they are themselves indoctrinated, for example, into mythical and stereotypical images of science, which they then in turn convey to students. Also, they are perhaps not aware of the importance of discussing also the presuppositions of science in science class – this is not something that is part of the science teaching tradition. Thus, teachers might not have any *intention* to indoctrinate students into biased and dubious ways to view science, but indoctrination does anyway seem to become the case. Was it foreseeable (Peterson 2007)? Yes, due to the large amount of research on students' views of the nature of science and the necessity of an explicit teaching concerning this (Lederman 2007), one can argue that it is foreseeable that teachers communicate stereotypical and mythical images of science, when not explicitly focused on doing something different. Yet, is this foreseeable for the accused teacher? Without extensive in-service training would it then be reasonable to accuse the teacher of indoctrination?

Discussion in philosophy of education points to the problems of accusing teachers of indoctrination when they have no such intent. We have, however, encountered some situations in the literature on indoctrination and science teaching where the intention to indoctrinate does not seem to be present, but where it anyway, somehow, seems to be about indoctrination. Therefore, we will return to the philosophy of education literature and look further into the discussions concerning the intention criterion and possible solutions to this dilemma.

11.4 Indoctrination Without Intention

A criticism raised in relation to the use of the intention criterion is that it excludes the possibility that teachers are unaware of their own intentions or that of the curricula writers (Bailey 2010). If "teachers have been educated within an indoctrinatory system, then it is possible that they are no more aware of the actual aims of schooling than their students: the teacher is both a victim and a perpetrator of indoctrination" (Bailey 2010, p. 276). In line with this, Momanu (2012) points to the fact that indoctrination in the literature has often been coupled to "interpersonal relationships", but that it sometimes also has been treated in relation to an "institutional level". Also, Huttunen discusses the intention criterion and points to this criterion not accounting for a possible indoctrination caused by the social structures rather than intended by the teacher: "Intention criterion focus attention on the teacher-student relationship and excludes the aspects of social systems or ideological processes" (Huttunen 2003, p. 10). He concludes that teachers' intentions to indoctrinate should not be used as the sole criterion for indoctrination – most teachers do not want to indoctrinate students, but one can see teaching practices where indoctrination seems to happen:

> how many teachers really want to indoctrinate students? … So, it is more meaningful to assume that the indoctrination happens unintentionally (by the structural causes). In this case, the traditional formulation of the intention criterion /…/ is useless. The intention criterion does not recognise indoctrination that is caused by the institutional or social structures. I presume that in the (post)modern teaching situation indoctrination occurs at the level of hidden curriculum (see Snyder 1971). No teacher or no educational institution openly and intentionally indoctrinates students, although many unreflected attitudes and

> beliefs (example racist and ethnocentric beliefs that would be rejected in the open and critical discourse) are transferred to the next generation through education. (Huttunen 2003, pp. 3–4)

That is, according to Huttunen, indoctrination, instead of being intended by the teacher, often happens unintentionally due to social or institutional structures – through the hidden curriculum (Snyder 1971).

Also, earlier writings about indoctrination and education open up for the possibility that indoctrination is not always intended by the teacher. Gregory and Woods argue that:

> The uncommitted teacher may have no intention of bringing about certain beliefs, but his position of authority within the institutional set-up, his role as teacher, lends powerful backing to his words; the system within which he operates endows his actions with a sense of purpose of which he, as an individual, may be quite unaware. (Gregory and Woods 1972/2010, p. 170)

Related to this they also speak about "the intentions of society" (Gregory and Woods 1972/2010, p. 170). This is in line with Huttunen (2003, p. 4) who states that "many unreflected [unexamined] attitudes and beliefs (example racist and ethnocentric beliefs that would be rejected in the open and critical discourse) are transferred to the next generation through education". Huttunen suggests that teaching that limits the possible perspectives for students instead of widening them, should be viewed as indoctrination:

> The teaching content should provide students with opportunities to construct their own creative and multi-dimensional view of reality. The teaching content should also promote students to engage critical self-reflection. Thus, if we want the teaching content to be non-indoctrinative, the teaching content should contribute to students' reflectivity towards those meaning perspectives that they have already adopted, and as well as toward those that are taught (see Mezirow 1991). … I consider content that limits students' meaning perspectives and minimizes as opposed to increases students' own power of judgement as indoctrinative. … The non-indoctrinative teaching content gives students both the freedom and faculty to determine their own differentiated identity, worldview and conduct of life. (Huttunen 2003, p. 13)

Huttunen's way of treating indoctrination is useful when trying to shed light on some frequent practices in science teaching, and is also a way to understand the cases referred to above: where intention does not seem to be there, but where it seems to be about indoctrination. To be able to develop reasoning further in this direction, we will now turn to examples of images of science communicated in the science classroom through the hidden curriculum. Thereafter, we will return to the concept of indoctrination and focus on indoctrination that possibly happens through the hidden curriculum, as suggested by Huttunen (2003). We will discuss the possibility of using the concept of indoctrination in this way to describe what is happening in science classrooms.

11.5 The Hidden Curriculum in the Teaching of Science: A Focus on Images of Science

The “hidden curriculum” concept was utilised by Snyder:

> I have found that a hidden curriculum determines, to a significant degree, what becomes the basis for all participants’ sense of worth and self-esteem. It is this hidden curriculum, more than the formal curriculum, that influences the adaptation of students and faculty. …. Though each curriculum has characteristics that are special to the particular setting, the presence of these hidden curricula importantly affects the process of all education. The similarities in these hidden curricula are at least as important as the differences. (Snyder 1971, xii–xiii)

This hidden curriculum could include how to master tasks given, how to communicate in science class, how to engage in laboratory work or problem solving, or how to attain high grades. Messages about these kinds of things, given by the teacher, are not always in line with the formal curriculum. Instead, there could be important differences between the formal curriculum and these other messages (the hidden curriculum) that influence life in the classroom.

In science teaching, there are messages about science itself, which are communicated in the classroom, in textbooks or elsewhere, but are not necessarily in line with how the formal curriculum describes the subject – these messages could be viewed as part of the hidden curriculum. It could be specific worldviews and ideologies communicated in the science class and therefore, associated with science by the students, as well as specific nature of science perspectives. Stereotypic and mythical images of science could very well be communicated in the teaching of science, even though the formal curriculum perhaps puts forward other nature of science perspectives. These types of views about science are sometimes communicated explicitly, but often also implicitly in science class.[10]

Schools can communicate a worldview through teaching in different ways, and two extreme cases can be seen (Proper et al. 1988). In one extreme, school explicitly presents and discusses a large variety of worldviews, while in the other extreme only a narrow span of worldviews is presented, and implicitly. The same could be said about possibilities for the communication of ideology as well as “nature of science” perspectives. In the second case (narrow span and implicit) it is relevant to discuss worldview (or ideology, or general nature of science perspectives) as part of the hidden curriculum (Kilbourn 1980). Often these worldviews, ideological perspectives, and nature of science perspectives are communicated implicitly as “companion meanings” (Roberts 1998). These companion meanings “can be either deliberately planned and incorporated in policy … or ‘unintentional’ (as with gender bias, world view bias, cultural bias, and many others)” (Roberts 1998, p. 11). In line with this, Östman states that the teaching, through these kinds of companion meanings, is communicating a view about science, nature and the relation between

[10] See, for example, Fourez (1988), Kilbourn (1980), Kilbourn (1980–1981), Roberts (1998) and Östman (1998).

humans and nature. To be able to see these companion meanings and be aware of their role, it is necessary to look for differences between the messages communicated and other possible alternative messages. This is done by noting what is not said, but could have been said (Östman 1998).

The examples given by Östman constitute examples of how views about science and specific worldviews are communicated in the teaching of science and become part of the hidden curriculum (see also Kilbourn 1980). Also, Fysh and Lucas (1998) discuss the problem with messages implicitly communicated about things not explicitly discussed in the teaching (in their case the relation between science and religion). Those implicit messages are important and students' views about the values and presuppositions of science are formed by them. In the extreme cases articulated by Proper and colleagues (1988) of how school science communicate worldviews, most such teaching is implicit rather than explicit. This means that even though science could be understood from the starting point of very different worldviews, ideologies and nature of science perspectives, this is most often not communicated in the science classroom. Here follow some examples.

11.5.1 Messages About the Nature of Science as Part of the Hidden Curriculum

Though often misunderstood in a way that makes a travesty of the pedagogical theory and practice of the founding positivists (Matthews 2004), logical positivism strongly influences much teaching of science (Aikenhead 2006). The above mentioned myths about science (McComas 1998) are reproduced in science classes through science concepts and models being presented as unchangeable, objective facts, and through traditional lab-work practices conveying images of a strict scientific method always being applicable. A large amount of research (see e.g. Lederman 2007) shows that students frequently express such views about the "nature of science" including, for example, that scientific research is an entirely rational, objective and universal enterprise, following the "scientific method" leading to absolute, objective facts about nature (Lederman 2007; McComas 1998).

Communicating such a small span of nature of science perspectives in the classroom leaves no room for students to scrutinize different possibilities and positions. Of course, a positivistic view is possible to combine with science, but so are many other views. Despite that many different perspectives are possible – Alters (1998, p. 48) argues that "no one agreed-on NOS exists" – uniform images of science are communicated in most science classrooms. This uniform image most often leaves no room for discussing or problematizing different possible perspectives on the nature of science. Instead, it could be argued that such images of science are part of the hidden curriculum in many science classes.

11.5.2 Messages About Worldview and Ideology as Part of the Hidden Curriculum

The image of science communicated in science class could also include science being associated with specific worldviews, such as scientistic (Stenmark 2004) and atheistic worldviews. Taber (2013, p. 153) states that "there is much potential for the image of science offered to pupils to be scientistic"; while Hansson and Redfors (2007a, b) and Hansson and Lindahl (2010, 2015) show that students often associate scientistic and atheistic views about the world with science. The question of how science is related to worldview has been discussed by scholars with different disciplinary backgrounds (see Matthews 2014, 2015, chap.10) and contributions to Matthews 2009). That there are different views concerning science and worldview is consistent with scholars having different views on other nature-of-science related issues.[11] Cobern (1991, 2000a) describes how scientists could be viewed to have some presuppositions about the world in common, but these presuppositions do not in themselves constitute a worldview. Instead these presuppositions are combined with others that differ between different scientists. Taber (2013) exemplifies how in this way it is possible to understand science with the starting point in different worldviews. This is, however, most often not communicated in the science class. Instead, frequently, a narrow span of worldviews is communicated, and taken for granted, in science class.

In addition, school science also communicates ideological perspectives. Fourez (1988) discussed ideology in relation to the teaching of science, stating that all science teaching is marked by ideology, but that there is often a large unawareness of this. Fourez gives an example of a teacher who argues that in his text book there is no ideology, only science. However, independent of the teacher's unawareness of the communication of ideology in the teaching of science, such messages are always there implicitly, in the teaching and in the text book (Fourez 1988). These messages will influence students' images of science. For example, there are scholars who argue that school science most often communicates modernistic and technology optimistic agendas (see above). However, these are not the only possible ideological starting points for engagement in science, and again the images communicated of science are narrow.

In the science class, often only a narrow span of worldviews, ideology, and nature of science perspectives are communicated and therefore tend to be associated with science by the students. Due to this students are not given access to different perspectives from which science can be understood. This specific narrow span is often not part of the formal curriculum, but something that influences what is happening in the science classrooms and how science is understood by students. These

[11] An individual's view about science and religion depends on her/his view about different nature of science issues), but also on the individual's view about religion, see Stenmark (2004) for an in-depth discussion on the relationship between science and religion.

messages could be viewed as part of the hidden curriculum in many science classes around the world.

11.6 Indoctrination in Science Class Through the Hidden Curriculum

Huttunen (2003) suggests that indoctrination is not always the intent of the teacher, but that it could be fruitful to think of indoctrination as something that also happens due to institutional structures, through the hidden curriculum. The hidden curriculum includes a lot of different aspects, and the ones focused on here are messages communicated about science itself – messages that most often are not part of the formal curriculum but nevertheless have great impact on students' images of science. For example, there are plenty of examples in the literature showing how science teaching communicates messages about science being a body of unchangeable, objective, universal facts; science being the same thing as scientism and science being associated with modernism (see above). These views are so frequent among teachers and students that they could be viewed as part of a hidden curriculum shared by many science classes around the world. Teachers and students are part of the social structures reproducing these images of science. While it would have been possible to communicate a wide span of perspectives in respect of worldviews, ideologies and nature of science perspectives, this is most often not what is happening. Instead, only a narrow span of perspectives are presented to the students, and frequently this is also done implicitly (Proper et al. 1988). It could be argued that these taken-for-granted and unproblematised messages constitute an attempt to indoctrinate students. In such a classroom where only a narrow span of perspectives is communicated, science is distorted for the students.

In these cases, it is not necessarily about teachers wanting to indoctrinate students (most teachers have good intentions), but something that happens unintentionally through the hidden curriculum (Huttunen 2003). Due to this, the traditional intention criterion is not fulfilled. However, it could be argued, in line with what Huttunen suggests, that teachers – as part of the school science institution – have used their "privileged role to influence those under his charge in a manner which is likely to distort their ability to assess the evidence on its own merit" (Snook 1972, p. 66). However, this may not always be the intention of the teacher. Also the teacher could have been indoctrinated into associating science with for example positivistic, scientistic and modernistic views. Not knowing what they are doing, the teachers contribute to a reproduction of the association between science and these specific perspectives on science. This distorts science for these indoctrinated students, who lose their possibility to engage in science with the starting point in their own ideological and worldview perspectives. Hansson and Lindahl (2010) shows how students' relations to science (good or bad) could partly be understood from such differences between students' own worldviews and the type of worldview they associate with science. Huttunen considers:

> content that limits students' meaning perspectives and minimizes as opposed to increases students' own power of judgement as indoctrinative. … The non-indoctrinative teaching content gives students both the freedom and faculty to determine their own differentiated identity, worldview and conduct of life. (Huttunen 2003, p. 13)

Thus, not problematizing and discussing different nature of science perspectives as well as science in relation to worldview and ideology, but instead only implicitly communicating a narrow span of views, indeed, according to this definition of the concept, is indoctrination. Thus, it is indoctrination both with the starting point in the content criterion (controversial content being communicated as non-controversial), and the consequence criterion (the teaching limits, rather than broadens, students' meaning perspectives). Taking the hidden curricula into account, much science teaching could be viewed as an attempt to indoctrinate students into specific views about science, even though most teachers have no such intent.

That the result of such teaching would be indoctrination is foreseeable, due to the large body of literature on students' views upon science. However, the one responsible for this indoctrination through the hidden curriculum is not only the teacher (who might have no intention of indoctrinating students), but the whole system (for which it is foreseeable that much teaching today is guilty of indoctrinating students into very specific views about science). Thus, it is the system as a whole that should be held guilty of indoctrinating students in science classes. This includes teachers, but also textbook authors, curriculum developers, teacher education and science education researchers – who all are part of this indoctrination. All should do their part to counteract this pattern.

11.7 Conclusion

The concept of indoctrination has not been given much attention in science education. Instead, most texts about indoctrination are about political and religious education. However, we have also seen that there are a number of different situations in which scholars have found indoctrination to be a fruitful concept in respect of science education. As we have seen here, with different definitions of the concept, these cases become more or less relevant to speak about as indoctrination.

This chapter outlined what it would mean to follow the line of reasoning suggested by Huttunen (2003) – which includes the institutional level and the hidden curriculum, in the concept of indoctrination. With this use of the concept much science teaching will be guilty of indoctrinating students, due to unproblematized and taken for granted views about the nature of science, worldview and ideology. As well as sticking to teaching traditions where science is mainly taught as "facts and lab-work" (Leden et al. 2015), where the aim is to change the belief (rather than understanding), and where reasons for “facts” are not given. Such a teaching could result in students’ rationality being by-passed and their autonomy threatened.

Scholars have identified this situation in the teaching of science, and also pointed to these practices as a hindrance for a meaningful and pluralistic science education, as well as for a pluralistic science. Empirical studies has pointed to the risk that students associating science with specific worldviews and values, but who themselves not share these views, tend to choose not to study science when having the choice (Hansson and Lindahl 2010; Krogh and Thomsen 2005; Worthley 1992). For example, a Swedish case study indicate that students with worldviews very different from the ones they associate with science tend to exclude themselves from science intense programmes (Hansson and Lindahl 2010). Indoctrination of students into specific ways of viewing science could therefore have consequences for students’ possibilities to engage in science, and could also have consequences in respect of choice of study profiles.

Stenmark argues that it is important that “the scientific community consists of people with different ideological or religious backgrounds so that the research topics undertaken and the questions asked reflect the interests of different groups of people” (Stenmark 2004, p. 220–221). To accomplish such a pluralistic science, it is important that students are provided with examples of how science could be engaged in from very different starting points. In this way, students with different worldviews, ideologies and perspectives on the nature of science get the possibility to engage in science in ways that they find meaningful. However, the present state is far from that. Instead, specific images of science are part of the hidden curriculum in most science classes around the world.

To label this “indoctrination” perhaps sounds harsh, but it is, as argued here, fair. To call things by their right name can shed light on the state of affair, and perhaps function as a starting shot for breaking the traditions of science teaching that result in indoctrination processes taking place in science classes all over the world.

References

Abd-El-Khalick, F. (2012). Nature of science in science education: Toward a coherent framework for synergistic Research and Development. In B. J. Fraser, K. Tobin, & C. McRobbie (Eds.), *Second international handbook of science education* (Vol. 2, pp. 1041–1060). Berlin: Springer.

Aikenhead, G. S. (1996). Science education: Border crossing into the subculture of science. *Studies in Science Education, 27*, 1–52.

Aikenhead, G. S. (2006). *Science education for everyday life: Evidence-based practice*. New York: Teachers College Press.

Allen, N. J., & Crawley, F. E. (1998). Voices from the bridge: Worldview conflicts of Kickapoo students of science. *Journal of Research in Science Teaching, 35*(2), 111–132.

Alters, B. J. (1997). Whose nature of science? *Journal of Research in Science Teaching, 34*(1), 39–55.

Ashton, E., & Watson, B. (1998). Values education: A fresh look at procedural neutrality. *Educational Studies, 24*(2), 183–193.

Bailey, R. (2010). Indoctrination. In R. Bailey, R. Barrow, & D. Carr (Eds.), *SAGE handbook of philosophy of education*. London: SAGE Publications Ltd.
Bencze, L., & Carter, L. (2011). Globalizing students acting for the common good. *Journal of Research in Science Teaching, 48*(6), 648–669.
Bencze, L., & Alsop, S. (Eds.). (2014). *Activist science and technology education*, *Cultural studies of science education* (Vol. 9). Dordrecht: Springer.
Bobel, C. (2006). "take this class if you like to be brainwashed": Walking the Knife's edge between education and indoctrination. *Human Architecture, 4*, 359.
Brandt, C. (2007). Scientific discourse in the academy: A case study of an American Indian undergraduate. *Science Education, 92*, 825–847.
Callan, E., & Arena, D. (2009). Indoctrination. In H. Siegel (Ed.), *The Oxford handbook of philosophy of education*. New York: Oxford University Press.
Clough, M. P. (2006). Learners' responses to the demands of conceptual change: Considerations for effective nature of science instruction. *Science & Education, 15*(5), 463–494.
Cobern, W. W. (1991). *World view theory and science education research*, *NARST monograph no. 3*. Manhattan: National Association for Research in Science Teaching.
Cobern, W. W. (1993). College students' conceptualizations of nature: An interpretive world view analysis. *Journal of Research in Science Teaching, 30*(8), 935–951.
Cobern, W. W. (1996). Worldview theory and conceptual change in science education. *Science Education, 80*(5), 579–610.
Cobern, W. W. (2000a). *Everyday thoughts about nature*. Dordrecht: Kluwer.
Cobern, W. W. (2000b). The nature of science and the role of knowledge and belief. *Science & Education, 9*, 219–246.
Cobern, W. W. (2004). Apples and oranges: A rejoinder to Smith and Siegel. *Science & Education, 13*, 583–589.
Cobern, W. W., Gibson, A. T., & Underwood, S. A. (1999). Conceptualizations of nature: An interpretive study of 16 ninth graders' everyday thinking. *Journal of Research in Science Teaching, 36*(5), 541–564.
Couló, A. C. (2014). Philosophical dimensions of social and ethical issues in school science education: Values in science and in science classrooms. In M. R. Matthews (Ed.), *International handbook of research in history, philosophy and science teaching* (Vol. II). Dordrecht: Springer.
Cuypers, S. E., & Haji, I. (2006). Education for critical thinking: Can it be non-indoctrinative? *Educational Philosophy and Theory, 38*(6), 723–743.
DiGiuseppe, M. (2014). Representing nature of science in a science textbook: Exploring author-editor-publisher interactions. *International Journal of Science Education, 36*(7), 1061–1082.
El-Hani, C. N., & Mortimer, E. F. (2007a). Multicultural education, pragmatism, and the goals of science education. *Cultural Studies of Science Education, 2*, 657–702.
El-Hani, C. N., & Mortimer, E. F. (2007b). Understanding typically yields belief: A neglected point in Hoffmann's reaction to our idea of "culturally sensitive science education". *Cultural Studies of Science Education, 2*(3). doi:10.1007/s11422-007-9064-y.
Flew, A. (1972/2010). Indoctrination and doctrines. In I. A. Snook (Ed.), *Concepts of indoctrination. Philosophical essays*. Abingdon: Routledge & Kegan Paul.
Fourez, G. (1988). Ideologies and science teaching. *Bulletin of Science, Technology & Society, 8*, 269–277.
Fysh, R., & Lucas, K. B. (1998). Religious beliefs in science classrooms. *Research in Science Education, 28*(4), 399–427.
Gatchel, R. H. (1972/2010). The evolution of the concept. In I. A. Snook (Ed.), *Concepts of indoctrination. Philosophical essays*. Abingdon: Routledge & Kegan Paul.
Green, T. F. (1972). Indoctrination and beliefs. In I. A. Snook (Ed.), *Concepts of indoctrination. Philosophical essays*. Abingdon: Routledge & Kegan Paul.
Gregory, I. M. M., & Woods, R. G. (1972/2010). In I. A. Snook (Ed.), *Concepts of indoctrination. Philosophical essays*. Abingdon: Routledge & Kegan Paul.

Hansson, L. (2014). Students' views concerning worldview presuppositions underpinning science: Is the world really ordered, uniform, and comprehensible? *Science Education, 98*(5), 743–765.
Hansson, L., & Lindahl, B. (2010). "I have chosen another way of thinking" Students' relations to science with a focus on worldview. *Science & Education*, *19*, 895–918.
Hansson, L., & Lindahl, B. (2015). Students, science and scientism: A story about resistance. *Proceedings from the IHPST Thirteenth Biennial International Conference*, Rio de Janeiro. Retrieved from http://ihpst.net/content.aspx?page_id=22&club_id=360747&module_id=187166
Hansson, L., & Redfors, A. (2006). Swedish upper secondary students' views of the origin and development of the universe. *Research in Science Education, 36*, 355–379.
Hansson, L., & Redfors, A. (2007a). Physics and the possibility of a religious view of the universe: Swedish upper secondary students' views. *Science & Education, 16*, 461–478.
Hansson, L., & Redfors, A. (2007b). Upper secondary students in group discussions about physics and our presuppositions of the world. *Science & Education, 16*, 1007–1025.
Hansson, L., & Redfors, A. (2013). Lower secondary students' views in astrobiology. *Research in Science Education, 43*(5), 1957–1978.
Hodson, D. (2014). Becoming part of the solution: Learning about activism, learning through activism, learning from activism. In L. Bencze & S. Alsop (Eds.), *Activist science and technology education*, *Cultural studies of science 9*. Dordrecht: Springer.
Hoffman, M. H. G. (2007). Learning without belief change? *Cultural Studies of Science Education, 2*(3). doi:10.1007/s11422-007-9064-y.
Huttunen, R. (2003). Habermas and the Problem of Indoctrination. In M. Peters, T. Besley, A. Gibbons, B. Žarnić, & P. Ghiraldelli (Eds.), *The Encyclopaedia of Educational Philosophy and Theory.* Retrieved from http://eepat.net/doku.php?id=habermas_and_the_problem_of_indoctrination
Jickling, B. (2003). Environmental education and environmental advocacy: Revisited. *The Journal of Environmental Education, 34*(2), 20–27.
Kearney, M. (1984). *World view*. Novato: Chandler & Sharp.
Kilbourn, B. (1980). World views and science teaching. In H. Munby, G. Orpwood, & T. Russell (Eds.), *Seeing curriculum in a new light. Essays from science education* (pp. 34–43). OISE Press/The Ontario Institute for Studies in Education.
Kilbourn, B. (1980–1981). World views and curriculum. Interchange, 11(2), 1–10.
Kilpatrick, W. H. (1972). Indoctrination and respect for persons. In I. A. Snook (Ed.), *Concepts of indoctrination. Philosophical essays*. Abingdon: Routledge & Kegan Paul.
Knain, E. (2001). Ideologies in school science textbooks. *International Journal of Science Education, 23*(3), 319–329.
Krogh, L. B., & Thomsen, P. V. (2005). Studying students' attitudes towards science from a cultural perspective but with a quantitative methodology: Border crossing into the physics classroom. *International Journal of Science Education, 27*(3), 281–302.
Laura, R. S. (1983). To educate or to indoctrinate: That is still the question. *Educational Philosophy and Theory, 15*(1), 43–55.
Leahy, M. (1990). Indoctrination, evangelization, catechesis and religious education. *British Journal of Religious Education, 12*(3), 137–144.
Leden, L., Hansson, L., Redfors, A., & Ideland, M. (2015). Teachers' ways of talking about nature of science and its teaching. *Science & Education, 24*(9–10), 1141–1172.
Lederman, N. G. (2007). Nature of science: Past, present, and future. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of research on science education* (pp. 831–879). Mahwah: Lawrence Erlbaum Associates.
Lee, H., Yen, C.-F., & Aikenhead, G. S. (2012). Indigenous elementary students' science instruction in Taiwan: Indigenous knowledge and western science. *Research in Science Education, 42*(6), 1183–1199.
Matthews, M. R. (1998). In defense of modest goals when teaching about the nature of science. *Journal of Research in Science Teaching, 35*(2), 161–174.
Matthews, M. R. (2004). Reappraising positivism and education: The arguments of Philipp Frank and Herbert Feigl. *Science & Education, 13*(1–2), 7–39.

Matthews, M. R. (Ed.). (2009). *Science, worldviews and education*. Dordrecht: Springer.
Matthews, M. R. (2014). Science, worldviews and education. In M. R. Matthews (Ed.), *International handbook of research in history, philosophy and science teaching* (pp. 1585–1635). Dordrecht: Springer.
Matthews, M. R. (2015). *Science teaching: The contribution of history and philosophy of science*. New York: Routledge.
McComas, W. F. (1998). The principal elements of the nature of science: Dispelling the myths. In W. F. McComas (Ed.), *The nature of science in science education: Rationales and strategies* (pp. 53–70). Dordrecht: Kluwer Academic.
Medawar, P. (1961/1996). Is the scientific paper a fraud? In P. Medawar (Ed.), *The strange case of the spotted Mice and other classic essays on science*. Oxford: Oxford University Press.
Mohanan, K. P. (2000). Indoctrination in linguistics education. Retrieved from http://www.iiser-pune.ac.in/~mohanan/educ/ling-ed.pdf.
Momanu, M. (2012). The pedagogical dimension of indoctrination: Criticism of indoctrination and the constructivism in education. *Meta: Research in Hermeneutics, Phenomenology, and Practical Philosophy, IV*(1), 88–105.
Moore, W. (1972/2010). Indoctrination and democratic method. In I. A. Snook (Ed.), *Concepts of indoctrination. Philosophical essays*. Abingdon:Routledge & Kegan Paul.
Öhman, J. (2007). The ethical dimension of ESD–Navigating between the pitfalls of indoctrination and relativism. In I. Björneloo & E. Nyberg (Eds.), *Drivers and barriers for implementing learning for sustainable development in pre-school through upper secondary and teacher education*, 43. UNESCO, Education for Sustainable Development in Action Technical Paper N°4.
Östman, L. (1998). How companion meanings are expressed by science education discourse. In I. D. A. Roberts & L. Östman (Eds.), *Problems of meaning in science curriculum* (pp. 54–70). New York: Teacher College Press.
Östman, L. (2010). Education for sustainable development and normativity: A transactional analysis of moral meaning-making and companion meanings in classroom communication. *Environmental Education Research, 16*(1), 75–93.
Pedretti, E. G., Bencze, L., Hewitt, J., Romkey, L., & Jivraj, A. (2008). Promoting issues-based STSE perspectives in science teacher education: Problems of identity and ideology. *Science & Education, 17*(8–9), 941–960.
Peterson, B. A. (2007). Holding teachers accountable for indoctrination: A reexamination of I. A. Snook's Notion of "Intent". *Philosophy of Education.*
Poole, M. W. (1995). *Beliefs and values in science education*. Buckingham: Open University Press.
Poole, M. W. (1998). Science and science education: A Judeo-Christian perspective. In W. W. Cobern (Ed.), *Socio-cultural perspectives on science education. An international dialogue* (pp. 181–201). Dordrecht: Kluwer.
Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a scientific conception toward conceptual change. *Science Education, 66*(2), 211–227.
Proper, H., Wideen, M. F., & Ivany, G. (1988). World view projected by science teachers: A study of classroom dialogue. *Science Education, 72*(5), 547–560.
Qablan, A., AL-Ruz, J. S., Khasawneh, S., & Al-Omari, A. (2009). Education for sustainable development: Liberation or indoctrination? An assessment of faculty members' attitudes and classroom practices. *International Journal of Environmental & Science Education, 4*(4), 401–417.
Qablan, A., Southerland, S. A., & Saka, Y. (2011). "my job isn't to tell them what to think": The fear of indoctrination and how it shapes education for sustainable development. *Electronic Journal of Science Education, 15*(2).
Reiss, M. (1993). *Science education for a pluralist society*. Buckingham: Open University Press.
Roberts, D. A. (1998). Analysing school science courses: The concept of companion meaning. In D. A. Roberts & L. Östman (Eds.), *Problems of meaning in science curriculum* (pp. 5–12). New York: Teacher College Press.
Schulz, R. M. (2014). Philosophy of education and science education: A vital but underdeveloped relationship. In M. R. Matthews (Ed.), *International handbook of research in history, philosophy and science teaching* (Vol. II). Dordrecht: Springer.

Selby, D. E. (2014). Education for sustainable contraction as appropriate response to global heating. In L. Bencze & S. Alsop (Eds.), *Activist science and technology education*, *Cultural studies of science 9*. Dordrecht: Springer.
Sinatra, G. M., Southerland, S. A., McConaughy, F., & Demastes, J. W. (2003). Intentions and beliefs in students' understanding and acceptance of biological evolution. *Journal of Research in Science Teaching, 40*(5), 510–528.
Smith, M. U., & Siegel, H. (2004). Knowing, believing, and understanding: What goals for science education? *Science & Education, 13*, 553–582.
Snook, I. A. (1972). *Indoctrination and education*. Abingdon: Routledge & Kegan Paul.
Snook, I. A. (1972/2010). Concepts of indoctrination. Philosophical essays. Abingdon: Routledge & Kegan Paul.
Snyder, B. R. (1971). *The hidden curriculum*. New York: Alfred A. Knopf.
Solli, A., Bach, F., & Åkerman, B. (2014). Learning to argue as a biotechnologist: Disprivileging opposition to genetically modified food. *Cultural Studies of Science Education, 9*(1), 1–23.
Southerland, S. A., & Scharmann, L. C. (2013). Acknowledging the religious beliefs students bring into the science classroom: Using the bounded nature of science. *Theory Into Practice, 52*(1), 59–65.
Southerland, S. A., Sinatra, G. M., & Matthews, M. R. (2001). Belief, knowledge, and science education. *Educational Psychology Review, 13*(4), 325–351.
Stenmark, M. (2001). *Scientism: Science, ethics and religion*. Aldershot: Ashgate Science and Religion Series.
Stenmark, M. (2004). *How to relate science and religion: A multidimensional model*. Michigan: W. B. Eerdmans Publishing.
Stolzenberg, N. M. (1993). "he drew a circle that shut me out": Assimilation, indoctrination, and the paradox of a liberal education. *Harvard Law Review, 106*, 581–667.
Taber, K. S. (2013). Conceptual frameworks, metaphysical commitments and worldviews: The challenge of reflecting the relationships between science and religion in science education. In N. R. Mansour & Wegerif (Eds.), Science education for diversity. Theory and Practice. Springer. Dordrecht
Tabone, C. P. (2011). Environmental education under assault: Can instructors teach environmental science without fear? *Interdisciplinary Environmental Review, 12*(2), 146–153.
Treagust, D. F., & Duit, R. (2008). Conceptual change: A discussion of theoretical, methodological and practical challenges for science education. *Cultural Studies of Science Education, 3*, 297–328.
van Eijck, M., & Roth, W.-M. (2011). Cultural diversity in science education through *Novelization*: Against the *Epicization* of science and cultural centralization. *Journal of Research in Science Teaching, 48*(7), 824–847.
White. (1972/2010). Indoctrination and intentions. In I. A. Snook (Ed.), *Concepts of indoctrination. Philosophical essays*. Abingdon: Routledge & Kegan Paul.
Wilson, J. (1964). Education and indoctrination. In T. H. B. Hollins (Ed.), *Aims in education: The philosophic approach* (pp. 23–46). Manchester: University of Manchester Press.
Wilson. (1972). Indoctrination and rationality. In I. A. Snook (Ed.), *Concepts of indoctrination. Philosophical essays*. Abingdon: Routledge & Kegan Paul.
Worthley, J. S. (1992). Is science persistence a matter of values? *Psychology of Women Quarterly, 16*, 57–68.

Chapter 12
Warranted Indoctrination in Science Education

Paul A. Wagner

A much-debated educational question has been: What is the legitimate role of indoctrination in education, and more specifically in science education? Contrary to many opinions, the noun *indoctrination* does not name a process or a set of processes; it does not denote any malevolent intent on the part of an indoctrinator; nor does it denote the value or epistemic soundness of any content resulting from one or more processes employed by an indoctrinator. Each of these claims will be made clear in the explanations which follow as will the conclusion that the noun indoctrination is best understood as a "benchmark" term and nothing more. It is a valuable benchmark term and provides generic license for pedagogical practices that lead to firmly held beliefs without the benefit of epistemic grounding.

12.1 Some History

The concept of indoctrination suffered a turbulent past during much of the last century (Wagner 1981, 1990). Appreciation of the Progressive Education movement and fear of practices such as the indoctrination of those in Nazi youth programs caused the concept of indoctrination to fall into disrepute. Western ideological fears prompted by the rise of the Cold War turned the connotation of the concept from a perceived good to a perceived evil. Many troubling practices were increasingly *affiliated with* the concept by politically sensitive scholars.

At the extreme, British philosopher Anthony Flew declared, albeit free from any definitional source, that indoctrination is a matter of implanting firm conviction in the truth of doctrines that are "…known to be false or at least not known to be true (Flew 1966, p. 282)." A few years later another British scholar John Wilson similarly

P.A. Wagner (✉)
Institute for Logic and Cognitive Studies, University of Houston, Houston, TX, USA
e-mail: wagner@uhcl.edu

M.R. Matthews (ed.), *History, Philosophy and Science Teaching*, Science: Philosophy, History and Education, DOI 10.1007/978-3-319-62616-1_12

dictated that indoctrination is "…to take over [the child's} consciousness" (Wilson 1972, p. 22 and Wilson 1964). A variety of similar ideological definitions of indoctrination were entertained moving from the 1960s into the 1980s as evidenced in Ivan Snook's anthology titled, *Concepts of Indoctrination* (Snook 1972b). Snook's own position, developed in his monograph, *Education and Indoctrination* (Snook 1972a), echoed much the same alarm as the authors in his edited volume.

The alarm of these post-war and Cold War scholars was misdirected. They took recent connotations of the term indoctrination and assigned malignant teaching practices to the meaning of the term itself. This was unnecessary. Drill and grill teaching practices had been denounced by progressive educators for years. Practices that stunted intellectual growth and substituted predictable behaviors in their stead had been denounced for years and continue to be denounced to this day. All that is well and good. But to bundle objection to malignant teaching practices with analysis of a common and well entrenched term such as indoctrination was likely to generate jargon and linguistic hair-splitting among scholars while practical advice to teachers lingered by the wayside.

The philosopher Thomas Green was among the first to recognize that something about recent attitudes toward indoctrination may cause more distraction than clarity in managing classroom instruction. Green's recognition, as articulated in Ivan Snook's edited volume *Indoctrination and Education,* set his position distinctly apart from the other contributors (Green 1972).

Green acknowledged that some beliefs must be inculcated in students. This seems a straight-forward matter of entering into any new study or the learning of a new game. These inculcated beliefs however should never be such as to make reflection, repair, or the discarding of ineffectual beliefs impossible. Certainly all this seems true enough and had Green stopped there then there would be no need to revisit his position. Unfortunately Green did not stop there but rather went on to elaborate the concept of indoctrination to distinguish between teaching strategies that precluded or greatly inhibited any further questioning on the part of students, from evidentially-responsive teaching that allowed for later belief revision when appropriate.

This bit of well-intended analysis did not advance pedagogical theorizing as Green hoped. Refining the meaning of the term 'indoctrination' does little to repair misguided classroom practices. In the mid-1980s Harvey Siegel picked up Green's ambition in a book titled, *Educating Reason* (1988). Siegel recognized the practical importance of the distinction that animated Green's thinking.

Siegel uses an example of two children Janie and Johnny. If each child is inculcated in some belief, but say Johnny's belief cannot be rationally redeemed while Janie's can, then there is indoctrination in the first case but not in the second. The turning point for Siegel, as for Green, turns on two evaluations. First, if the initial inculcation of belief leads to irredeemable grasping of some belief that is the distinguishing feature of their technical notion of indoctrination. Second, the holding of irredeemable beliefs on the part of a student is de facto evidence of culpable fault on the part of the teacher or some prescribed instructional strategy (Siegel 1988, pp. 79–83). All of this is a lot of machinery to make distinctions that in the end are pragmatically unmanageable. Holding irredeemable beliefs is difficult to make sense of for any prescriptive purpose. How long must one wait before evaluating whether or not a student's inculcated belief is irredeemable by reason?

In addition, there are many causes for why a student may not redeem an inculcated belief with reason and many of those may have nothing to do with how the student was taught! For example, the student may simply be negligent in attending to a particular belief set as she passes through life! And there may be no reason for her to attend to certain acquired belief sets in her life as she lives it.

12.2 Clearing a Path

In what follows, the term will reduced to its simplest and most deeply entrenched historical meaning. The purpose of this reduction is to secure ease of application of the concept when and where it matters most namely, the time and place of instruction.

The social and biological sciences make clear that the inculcation of belief is necessary for humans to grow intellectually. Standard dictionaries make clear that a simple and modest definition of the term indoctrination offers greatest utility for purposes of bench-marking effective pedagogical practices.

The utility of any term is best grounded by simplifying the concept to its most basic denotative meaning (Sober 2015, p. 10–12). Determining whether objectionable practices are indoctrinative or not is not the same as analyzing whether or not such practices corrupt student education. And declaring such practices to be indoctrination is not the same as explaining why named practices are offensive by reference to some clear and unambiguous criteria for identifying offensive practices.

Pejorative reference to practices associated with indoctrination and decrying that they involve some misguided intent is not uncommon (Smith and Siegel 2004). Of course, misguided or worse, evil intent towards others is always a bad thing as is deliberately inculcating falsehoods in others. And certainly the destruction of critical thinking and diminishing personal autonomy is similarly objectionable. Each of these intents and practices thwarts the invitation for every learner to come together in a Great Conversation of Humankind (Wagner 2011, p. 394). Yet none of these is an element in any standard dictionary's primary definition of indoctrination.

Thomas Kuhn's *The Structure of Scientific Revolutions* (Kuhn 1962/1970) attracted so much attention because the idea is that entry into a paradigm entails adopting organizing principles common to the science at the time. That much Kuhn continues to stand by (Kuhn 1987, p.11). Whatever challenges continue regarding the coherence of Kuhn's arguments, one thing remains settled: namely that, entering a new discipline involves learning *context-dependent fundamentals*.

Following Sosa, the term 'context–dependent fundamentals' will henceforth refer to principles, doctrine and performative practices that must be learned *in order to engage those who already exhibit substantial expertise in a given discipline* (Sosa 2011, p. 238–239). There is no suggestion here that in each and every case a discipline specific set of context-dependent fundamentals creates a closed system. In some sciences, such as classical mechanics, this may be true but in many other sciences, such as population genetics and plate tectonics, there is a relatively narrow but open set of such fundamentals operative at any point in time.

12.3 Preliminary Definition

Indoctrination is neither a good nor an evil in itself. Judging the effects of indoctrination and in context may prompt a host of legitimate and timely concerns. However, the effects and context do not constitute the literal meaning of the term, either traditionally or in this exegesis.

Indoctrination is best *described* (as opposed to defined) as a dangerous good. Indoctrination in science is *good to the extent* it instills in students a useful conceptual foundation for doing science. This is to say, indoctrination is good to the extent that it makes possible greater student engagement with those more expert in a discipline or field of study. In contrast, indoctrination is *dangerous to the extent* it causes students to lose a sense of wonder, a passion for confirmation and a propensity to seek ever better understanding of the world. Furthermore, indoctrination is dangerous to the extent it causes students to disengage with experts and other specialists in a field or discipline, or causes students to lose interest in independently seeking further insight into the world through a never ending process of systematic trial and error.

In practice, fitting students with a set of beliefs and dispositions for which they are unable to provide justification is not always a bad thing—at least initially. In fact, practices culminating in indoctrination are often unavoidable as in situations where novice learners must be led to the threshold of creative inquiry in a discipline wholly novel to them. For example, take the common and rudimentary case of students learning the context-dependent fundamentals of written communication. No alphabet is particularly superior to any other. But given the context, the twists and turns of symbols acquire an evolutionary resiliency that make for a useful tool advancing communal access to common understanding.

In the United States, students are typically taught a song, the Alphabet Song. Once familiar with the alphabet, students begin reading, writing and moving forward towards participation in The Great Conversation in ways they never previously imagined. Being drilled on the alphabet or how to count with no grounds for justification (indoctrination) never prevented anyone from later engaging in science, philosophy, linguistics, critical theory and all contemporary disciplines which require written transactions of one kind or another.

When students first learn the elements of the periodic table, they have little grasp of why it is worth learning (Weinstein 2013, p.46). Teachers make a point of explaining atomic weights and the sterile nature of elements, but to the novice this is typically little more than information to be grasped and responded to on recognition tests. Little more can be expected early on. Without such directed (indoctrinative) learning, again to use Wiley's term, ritualized signaling, students have little chance to gain an independent grasp on the various disciplines, fields and other ways of looking at the world.

12.4 Indoctrination in the Sciences

Beginning students in every science are required to grasp basic semantics, inferential principles and, perhaps, dispositions and habits of observation (Wagner and Lucas 1977). As these context-driven fundamentals are acquired, students should then be invited to doubt, criticize hypothesize and consider systematic trial and error approaches to extort further information from nature. In general, this is how humans advanced individual and collective understanding across every generation. The process leads from early indoctrinative/ritualized signaling practices to greater theoretical strategies and the ability to notice anomalies in experimental observations (Wiley 2015, p. 124–5). As student understanding and management of autonomous reflection increase, directed instruction leading to indoctrination should decrease proportionately (Driver et al. 1996).

12.4.1 The Teaching of Genetics

As an example, consider the teaching of genetics. The context-driven fundamentals in biology at the time of Watson and Crick's childhood were as follows: Mendel and Ronald Fisher's theory of proportional probabilities of inheritance, Thomas Morgan's work with fruit flies exhibiting the potency of mutations, cells had non-porous membranes, eukaryotic cells had nucleus and were filled with cytoplasm protecting the nucleus. Watson and Crick and others of their generation would have been required to memorize these context-driven fundamentals in their early biological education (Wesson 1991, p. 289–90). There was no gene theory of information processing as of yet. There was no knowledge of ribosomes (a term Crick coined), the transmission of biological information for coding proteins within cytoplasm (a hunch Crick explored the year after discovering the structure of DNA) (Lane 2015, p. 7). There was no theory of mitochondria oxygen-releasing, energy engines, and no speculation regarding messenger RNA (Lane 2005, p. 16). Yet Watson and Crick, schooled in the context-driven fundamentals of biology at their time were able to use the knowledge they had to construct disciplined speculation about something as extraordinary as DNA and add to the set of context-driven fundamentals of the neo-Darwinian evolutionary science that they and folks like Carl Woese were revising and extending (Lane 2015, p. 7–9).

Forty years later students in high school were taught that every cell is an industrial center of activity with at least forty-three factories operating inside nearly every cell. Students are told that DNA contains chemical bases of four amino acids

(ACGT). They are also told that combinations of these amino acids code for proteins, and generate ribosome activity and genetic differentiation (Stolz et al. 2004). Students learn Lynn Margulis' startling discovery of a process called symbiosis inside the cell whereas previous generations had been taught there is only the dormant cytoplasm (Lane 2015, p. 30–37). High school curricula are making genetic coding a threshold concept in biological education (Smith and Good 1984).

Approaching 2020, the scientific context determining relevant fundaments continues to evolve. Students are still directly taught about cell membranes, meiosis, mietosis, nucleus, inheritance and mutation just as were Watson, Crick, Woese and others decades before. The additional context-driven fundamentals of the twenty-first century now incorporate ribosomes, genes as hybrid units of shape, amino acid proximity and information (Field and Davies 2015), as well as suspicions about the creative potential of something called epigenetics and environmental change (Carey 2015, p. 101). The size of the human genome, students are now taught, is approximately twenty to thirty thousand genes and not the one hundred thousand believed in the year 2000 (Lane 2015, p. 22–23). Students are told that humans and chimpanzees share as much as 98.3% of the same genomic make up but as data from the ENCODE Project flows in, it may turn out that non-coding "junk DNA" is critical to managing genetic information and differentiating humans from other primates as well as re-framing the problem of speciation generally (Carey 2015, p. 178–179).

No entry level biology student can understand what such a deluge of information means in any significant way (Lombroso et al. 2008). Even the public at large seems overwhelmed by all the evidence revealing genetic foundations of evolution (Miller et al. 2006). Nonetheless, through ritualized signaling/indoctrination, students are expected to buy into these facts. This information must stick if one day students are to speculate, doubt and otherwise meaningfully grapple with the complexities of genetics and evolution (Lawson and Weser 1990).

There is no way of entering into the deep and demanding study of genetics without first grasping some basic linguistic and conceptual tools, inferential practices and investigatory procedures that constitute the context-driven fundamentals (Smith and Adkinson 2010; Thompson and Stewart 2003). These basic tools and practices are no more simply discovered by students than do students simply discover a usable alphabet and theorize about its utility. Instead, students are introduced to adopt conceptual tools intended to transport them through the threshold of ritualized signaling and then into a new dimension of the Great Conversation. The same instructional pattern is repeated in the teaching of all science disciplines.

Instructional practices that exceed the required amount of indoctrination, work against students developing autonomy in science and beyond. Science educators must be careful not to treat all subject matter as if it is fundamental (El Hani and Mortimer 2007). If everything is taught as so much "mud thrown against a brick wall," in the hope that some will stick, then students are unlikely to recognize some ideas as "context-driven" and others as more promisingly resilient (Nisbett 2015,

p. 230–2). If all is determined as settled once and for all, learners may dismiss the need for critical review and inventive investigation.

The fact that creationism must rely wholly on indoctrinative *practices* discredits creationism in science education. But discrediting creationism doesn't make indoctrination a bad idea. It is only the *exhaustive* exploitation of indoctrinative practices that is pedagogically (and perhaps morally) objectionable. This is true of genetics and evolutionary science as much as it is for creationism. Any time instruction discourages apt questions, the curriculum becomes fossilized. In the teaching of every science, there must be a threshold demarcating the staged ending of indoctrinative instructional strategies (practices that aim for acquisition of facts, protocols and dispositions that students cannot remotely justify) and leading towards participation in a technical aspect of the Great Conversation.

12.5 Conclusion

In the end, two things matter when it comes to understanding the pedagogical significance of the concept of indoctrination. First, educators need to benchmark when indoctrinative practices are necessary given learner innocence of the fundamentals. Second, educators need to recognize when practices leading to indoctrination become excessive. This excessiveness alerts educators that current practices need to be curtailed and replaced with more dialogic exercises. Understanding indoctrination benchmarks for educators both when indoctrinative practices are necessary and when ritualistic signaling practices exceed their utility.

Students need indoctrination as herein defined, in order to approach the threshold of study in any new discipline. However, once learners are over the threshold, science educators need to identify the transition points wherein the focus of instruction steers away from constraining practices that are counter-productive to bringing students into the Great Conversation of Humankind.

When indoctrination continues unabated beyond the threshold required for novel speculation and criticism, new paths for student understanding are thwarted. Teacher respect for the moral agency of the student as an independent thinker and contributor to the science is threatened. In short, the student's eventual residence in The Great Conversation of Humankind is at risk. Such consequences are grave moral misdeeds.

Students must simply appropriate fundamentals of a discipline or field of study in order to begin developing any skills of independent investigation. This recognition of the limited but core value of indoctrinative practices leads to the following principles:

I. Indoctrinative practices are necessary in the initial stages of any new quest for disciplinary understanding.

II. The justification of such practices is limited to facts, principles, current investigatory strategies and semantics fundamental for understanding the discipline in its current scientific context.

   A. What is fundamental to a discipline or field of study is context dependent and made evident by the practices of currently engaged experts in the field (Sarkar 2007).
   B. Indoctrination should never exceed the minimum required for disciplined inquiry into a field of study in its current state.

III. Indoctrinative practices that prove excessive should be avoided.

   A. Such practices prove excessive when they discourage desire for independent investigation.
   B. Excessive use of practices which indoctrinate is morally offensive. It should be avoided when it limits rather than extends prospects for learner autonomous agency.

References

Carey, N. (2015). *Junk DNA: A journey through the dark matter of the genome*. New York: Columbia University Press.

Driver, R., Leach, J., Millar, R., & Scott, P. (1996). *Young people's images of science*. Buckingham: Open University Press.

El Hani, C. N., & Mortimer, E. F. (2007). Multicultural education, pragmatism, and the goals of science teaching. *Cultural Studies of Science Education, 2*, 657–702.

Field, D., & Davies, N. (2015). *Biocode: The new age of genomics*. Oxford: Oxford University Press.

Flew, A. (1966). What is indoctrination? *Studies in Philosophy and Education, 4*(3), 281–306.

Green, T. F. (1972). Indoctrination and beliefs. In I. Snook (Ed.), *Concepts of indoctrination* (pp. 25–46). New York: Routledge & Kegan Paul.

Kuhn, T. S. (1962/1970). *The structure of scientific revolutions*. Chicago: University of Chicago Press.

Kuhn, T. S. (1987). *Black body theory and the quantum discontintuity*. Chicago: University of Chicago Press.

Lane, N. (2005). *Power, sex and suicide: Mitochondria and the meaning of life*. Oxford: Oxford University Press.

Lane, N. (2015). *The vital question: Energy, evolution and the origins of complex life*. New York: W. W. Norton.

Lawson, A. E., & Weser, J. (1990). The rejection of non-scientific beliefs about life: Effects of instruction and reasoning skills. *Journal of Research in Science Teaching, 27*(6), 589–606.

Lombroso, T., Thanukos, A., & Weisberg, M. (2008). The importance of understanding the nature of science for accepting evolution. *Evolution Education and Outreach, 1*, 290–298.

Miller, J. D., Scott, E. C., & Okamoto, S. (2006). Public acceptance of evolution. *Science, 313*, 765–766.

Nisbett, R. (2015). *Mindware: Tools for smart thinking*. New York: Strauss, Giroux & Farrar.

Sarkar, H. (2007). *Group rationality in scientific research*. Cambridge: Cambridge University Press.

Siegel, H. (1988). *Educating reason: Rationality, critical thinking, and education*. New York: Routledge.

Smith, M. U., & Good, R. (1984). Problem-solving and classical genetics: Successful v. unsuccessful performance. *Journal of Research in Science Teaching, 21*, 895–812.

Smith, M. U., & Siegel, H. (2004). Knowing, believing and understanding: What goals for science education? *Science and Education, 13*, 553–562.

Smith, M. U., & Adkinson, L. R. (2010). Updating the model definition of the gene in the modern genomic era with implications for instruction. *Science & Education, 19*(1), 1–20.

Snook, I. (1972a). *Indoctrination and education*. New York: Routledge & Kegan Paul.

Snook, I. A. (Ed.). (1972b). *Concepts of indoctrination*. London: Routledge & Kegan Paul.

Sober, E. (2015). *Ockham's razors: A user's manual*. Cambridge: Cambridge University Press.

Sosa, E. (2011). *Reflective knowledge: Apt belief and rational knowledge*. Oxford: Oxford University Press.

Stolz, K., Griffith, P. E., & Knight, R. (2004). How biologists conceptualize genes: An empirical study. *Studies in the History and Philosophy of Biological and Medical Sciences, 35*, 647–673.

Thompson, N., & Stewart, J. (2003). Genetics inquiry: Strategies and knowledge geneticists use in solving transmission genetics problems. *Science Education, 87*(2), 161–180.

Wagner, P. (1981). Indoctrination, Simon and ethical relativism. *Journal of Educational Thought, 15*(3), 187–194.

Wagner, P. (1990). Will education contain fewer surprises for students in the future? In V. Howard (Ed.), *Varieties of thinking: Recent research from the Harvard Philosophy of Education Research Center* (pp. 176–211). New York: Routledge.

Wagner, P. (2011). Isolationism and the possibility of truth. *Interchange, 42*(4), 389–408.

Wagner, P., & Lucas, C. (1977). Philosophic inquiry and the logic of elementary school science education. *Science Education, 61*(4), 549–558.

Weinstein, M. (2013). *Logic, truth and inquiry*. London: College Publications.

Wesson, R. (1991). *Beyond natural selection*. Cambridge, MA: MIT Press.

Wiley, R. (2015). *Noise matters: The evolution of communication*. Cambridge, MA: Harvard University Press.

Wilson, J. (1964). Education and indoctrination. In T. H. B. Hollins (Ed.), *Aims in education: The philosophic approach* (pp. 23–46). Manchester: University of Manchester Press.

Wilson, J. (1972). Indoctrination and rationality. In I. Snook (Ed.), *Concept of indoctrination* (pp. 17–24). New York: Routledge & Kegan Paul.

Name Index

A
Abd-El-Khalick, F., 168, 170–172, 178, 183, 184, 293
Addulhamid II, 77–80
Adorno, T., 44, 60, 61, 63, 64
Ahmed III, 72
Aikenhead, G.S., 72, 115, 116, 161, 204, 216, 263–265, 289, 298
Akkach, S., 70, 71, 93
Akural, S.M., 92
Allchin, D., 143, 144, 168, 169, 180
Alters, B.J., 168, 294, 298
Ambedkar, B., xiv
American Association of the Advancement of Science (AAAS), 5, 262
Antink, A., 263, 265
Aristokles, J., 79
Arons, A.B., 225, 242, 244
Ashton, E., 292
Ata, B., 84
Ataturk, M.K., 73, 80–84, 92
Ault, C.R., 151, 160

B
Bacon, F., 44, 49, 61, 62
Baggott, J., 129
Bailey, R., 283, 285, 289, 295
Bartos, S., 168
Bartos, S.A., 168
Basu, S.J., 263, 275
Bayle, P., 45, 70
Bencze, L., 292
Berkes, F., 111
Berkes, N., 68, 69, 73, 75–77, 79, 81, 85, 91
Bevilacqua, F., 236, 237
Bittner, R., 57
Bobel, C, 291
Bonneval, C.A., 73
Boran, B., 85
Boratav, P.N., 85
Brahe, T., 71
Braithwaite, R.B., 241
Brem, S.K., 268
Brickman, P., 262
Bridgman, P.W., 225, 241
Bristow, W., 47
Bruun, O., 4
Bunge, M., 24, 31, 33, 112, 119, 124, 236, 242
Butler, W., 273

C
Cabanis, P.J.G., 77
Callan, E., 283, 284
Capra, F., 12
Carter, L., 270, 292
Cassirer, E., 47, 50
Cemalettin Afgani, 79
Cevdet Pasha, 78
Ch'en, T.-H., 21, 22
Chinese Chi Research Centre, 26
Clavius, C., 13
Cobern, W.W., 288, 289, 294, 299
Collins, H.M., 143
Collins, S., 168, 263, 264
Comte, A., 81
Condit C.M., 265
Confucius, 17, 22
Coopersmith, J., 27, 237
Copernicus, N., 44, 49, 71, 73
Cordero, A., 100

M.R. Matthews (ed.), *History, Philosophy and Science Teaching*, Science: Philosophy, History and Education, DOI 10.1007/978-3-319-62616-1

Corsiglia, J., 110, 115
Couló, A.C., 291
Coyne, J., 47
Cuypers, S.E., 285

D
Dagher, Z.R., 169, 189
Davey, A., 263, 264
Davidson, N., 72
DeBoer, G.B., 262, 270
Deloria, V., 112, 115
Dempster, E.R., 263
Department of Education (USA), 271
Department of Energy (DoE) (USA), 25
Dervish Pasha, 78
Devitt, M., 119
Dewey, J., 83–85, 119, 124, 126, 128, 129, 131, 224, 263, 264, 268, 270, 272
d'Holbach, B., 77
Diderot, D., 45, 77
DiGiuseppe, M., 294
Dincerler, V., 89
Dobzhansky, T., 269, 270
Dorn, C., 84
Dotger, B.H., 270, 272
Dotger, S., 270, 272
Durant, J., 268
Duschl, R.A., 140, 143, 152, 168, 170

E
Edis, T., 89
Einstein, A., 8, 80, 205, 207, 210, 214, 223, 225, 227, 241
Eitel, E.J., 13, 15–21
El-Hani, C.N., 288, 289
Elkana, Y., 116, 226, 227, 236, 239, 240
Elmesky, R., 110
Emanuel, L.L., 265
Engels, F., 62
Erduran, S., 152, 160, 169, 189
Euclid, 13, 197, 216
Evans, E.M., 268

F
Falke, F., 83
Farrell, F., 104
Feinstein, N., 263, 264, 270, 273–275
Ferris, F.D., 265
Feynman, R., 25, 228, 236, 243
Field, S., 7, 31
Flew, A., 285, 307
Ford, M., 143, 153
Foucault, M., 62
Fourez, G., 297, 299
Fuat Pasha, 78
Fung, Y.-L., 22
Fysh, R., 298

G
Galileo, G., 13, 18, 27, 44, 49, 73, 221
Galle, J., 19
Gatchel, R.H., 283, 285
Gavroglu, K., 68
Gay, P., 45, 47, 69
Gellner, E., 107, 108
Gibbon, E., 45
Gil-Pérez, D., 263, 266
Glaserfeld, von, E., 121
Gokalp, Z., 82
Goldstein, R., 50
Gordin, M.D., 263
Gormally, C., 262
Gould, S.J., 47
Grandy, R., 170
Gray, J., 44, 59–61, 64
Green, T.F., 283, 285, 308
Gregory, I.M.M., 296
Griffin, D., 103, 116
Gunal, İ., 73, 78–80, 82, 83, 85
Guo, P., 7, 24

H
Habermas, J., 44, 47
Hansson, L., 27, 289, 290, 293, 294, 299, 300, 302
Hansson, S., 31
Harman, W., 27, 103, 104
Hashem Pasha, 79
Haverkos, K., 116
Hayrullah Efendi, 78
Hegel, G., 125
Hekim Ismail Pasha, 78
Hempel, C.G., 28, 29, 226, 227, 241
Herschel, W., 19
Hind, A.J, 172
Hodson, D., 168, 169, 262, 292
Horkheimer, M., 44, 60–64

Hugo, W., 263
Hume, D., 27, 45, 55
Huttunen, R., 284, 295, 296, 300, 301

I
Ibn Al-Haytham (Alhazen), 212, 215, 216
Ibrahim Sinasi, 81
Ihsanoglu, E., 70–72
Ileri, T., 86
Ilkin, S., 73, 74
Ingram, D., 172
Inhofe, J., 101
Irwin, A., 263
Irzik, G, 152, 168, 186, 187
Israel, J.I., 43, 45–50, 52–54, 57, 59, 61, 63, 69, 70, 93

J
James, M.C., 171, 184
James, W., 125, 196
Jenkins, E.J., 263, 264, 270, 274
Jenkins, E.W., 263
Jensen, M., 171, 184
Jimenez-Aleixandre, M.P., 147, 151, 160
Johnson, K., 263
Joule, J.P., 237, 238, 244, 248, 251–254, 256
Jungwirth, E., 170

K
Kahneman, D., 264
Kant, I., 18, 44, 48, 49, 54, 56–61, 119, 197
Kantorowicz, A., 83
Karaomerlioglu, A., 85, 86
Karatheodoris, K., 80
Karplus, R., 225, 240–244, 251, 252
Kearney, M., 294
Kelly, G.J., 141, 143–146, 148, 149, 155–160
Kepler, J., 44, 71, 215, 216
Khishfe, R., 168, 170, 171, 178, 181, 183, 184
Kilbourn, B., 297
Kilpatrick, W.H., 285, 291
Kirby, F., 85
Knain, E., 294
Kolstø, S.D., 263
Koyré, A., 18
Kucuk, B.H., 71, 72, 93
Kuhn, T.S., 28, 34, 154, 168, 207, 237, 240, 309
Kumas, K., 74
Kuscu, Ali, 71

L
Laudan, L., 30
Laugksch, E., 262, 270
Laura, R.S., 285, 294
Lave, J., 264
Layton, D., 263, 264
Le Verrier, U., 19
Leach, J.T., 142, 169, 172, 269, 311
Leahy, M., 287, 294
Leden, L., 301
Lederman N.G., 168, 171, 172, 178, 184, 203, 226, 295, 298
Lewis, J., 269
Lidar, M., 150
Lin, H., 26
Littre, E., 81
Locke, J., 45, 55
Longino, H.E., 141, 148, 158
Lotman, Yu., 205
Lutz, M., 262
Lynch, M., 158

M
MacFarlane, C., 77
MacGill, S., 263, 264
Mach, E., 28, 30, 195–197, 225, 228
Mahmud II, 73, 77
Mahner, M., 27, 112
Malche, A., 82
Mao, T.-T., 23, 24
Margenau, H., 215, 225, 241, 242
Margulis, L., 312
Marton, F., 208
Marx, K., 62, 64
Matthews, M.R., 3, 4, 6–8, 10–13, 15–22, 24, 25, 27–34, 143, 168, 178, 181, 226, 229, 241, 292–294, 299
McComas, W.F., 168, 293, 298
McConnell, M., 101
Medawar, P., 293
Meichtry, Y.J., 170
Mendelssohn, M., 44, 48, 56–58
Michelini, M., 245, 246
Millar, R., 168, 243, 245, 264, 267
Miller, J., 5, 311
Miricanyan, M., 74
Mohanan, K.P., 287
Momanu, M., 285, 295
Monk, M., 168, 237
Moore, W., 284, 285
Morrison, J.A., 172
Murad III, 71

Murkowski, L., 101
Mustafa Resit Pasha, 81
Muteferrikka, I., 75

N
National Center for Education Statistics (USA), 271
National Research Council (USA), 246
Needham, J., 17
Nehru, J., xiv
Nelson, S., 267
Newton, I., 27, 34, 44, 49, 58, 152, 208, 209, 217, 218, 221, 224
NGSS Lead States, 145, 269
Nichodemus, Y., 110
Nola, R., 43–45, 47–50, 52–58, 60, 62–64, 186
Norris, S.P., 141
Null, W., 257

O
Office of National Drug Control Policy (USA), 267
Ogawa, M., 111, 115
Ogborn, J., 243
Öhman, J., 291
Oliveira, A.W., 153
Olson, J.K., 168
Omoregbe, J., 110
Oncu, A., 82, 85, 89
Osborne, J., 168, 263, 264, 267
Östman, L., 298
Ozal, T., 88
Ozsoy, S., 84

P
Patiniotis, M., 68
Pavlik, S., 111, 112
Peat, F., 112–114
Pedretti, E.G., 291
Peirce, C., 117
Peterson, B.A., 286
Phillips, L., 141
Pigliucci, M., 125, 270
Pluta, W.J., 153
Pocock, J., 45
Poincare, H., 236, 243
Poole, M.W., 291
Popper, K.R., 26, 28, 120, 121, 227, 228
Posner, G.J., 208, 288
Proper, H., 293, 297
Ptolemy, 73, 207, 216
Ptolomey, C., 207

Q
Qablan, A., 291
Qadi Zadeh al-Rumi, 71

R
Raab, F., 172
Randi, J., 27
Ratcliffe, M., 168
Reagan, W.R., 88
Reichenbach, H., 214, 225
Renan, E., 81
Rennie, L.J., 263
Rescher, N., 118
Reveles, J.M., 154
Ricci, M., 13–15
Ritchie, S., 105
Ritskes, E., 116
Roberts, D.A., 262, 297
Rogers, E.M., 265
Rosengren, K.S., 268
Roth, W.M., 105
Rousseau, J-J., 45
Russell, B., 45, 47
Ryan, P., 101
Ryden, E., 8
Ryder, J., 172, 263, 270
Ryder, N., 264

S
Sabuncuoglu, S., 71
Said Pasha, 79
Sandoval, W.A., 153
Santoro, D.A., 83, 84, 92
Sarton, G., 226
Scharmann, L.C., 169, 171, 184, 273, 289
Schmidt, J., 48, 61
Schulz, R.M., 284
Schwab, J.J., 240, 256
Selby, D.E., 292
Selim III, 73
Shahjahan, R, 116
Shamos, M., 262, 263
Shimony, A., 46, 47, 50, 52
Shortland, M., 268
Siegel, H., 308, 309
Siemsen, H., 196, 198–200

Sinatra, G.M., 173, 290
Sirer, R.S., 85
Smith, L., 101
Smith, M.U., 169, 171, 184, 261–267, 269, 271–276, 309, 312
Snively, G., 110, 111
Snook, I.A., 285–287, 300, 308
Snyder, B.R., 284, 295, 297
Solli, A., 292
Somel, S.A., 74
Somer, M., 93
Southerland, S.A., 288, 289
Sperber, D., 53
Spinoza, B., 44, 45, 70
Steinbach, U., 92
Stenmark, M, 299, 302
Stolzenberg, N.M., 284

T
Taber, K.S., 293, 299
Tahir Munif Efendi, 78
Tahsin Efendi, 79
Takao, A.Y., 146, 158
Tamir, P., 170
Tang, Y., 22
Taqii-al-Din, 71
Tatersall, I., 270
Tekeli, İ., 73, 74
Tevfik, R., 82
Thatcher, M., 88
Thomas, G., 268
Tillotson, J., 269, 270, 272
Tippins, D., 119, 120
Tobin, K., 9, 32
Tonguc, I.H., 85
Too, L., 12
Treagust, D.F., 288
Trigault, N., 14
Trump, D., 101, 123
Tversky, A., 264

U
Upton, F., 101

V
van Eijck, M., 293
Vilches, A., 263, 266
Vision, G., 125
von Gunten, C.F., 265
Vygotsky, L., 159

W
Watson, J.D., 274
Wegman, M., 32
Weinberg, S., 205, 216, 227, 229
Weiner, J., 273
Wen, K., 32
Wickman, P.-O., 150, 153, 158, 159
Williams, R., 118
Wilson, J., 307, 308
Wittgenstein, L., 45, 150, 158
Wofford, K.V., 86
Wolpert, L., 100, 117

X
Xin, Y., 26

Y
Yalcin, H.C., 82
Yalcinkaya, M.A., 76
Yucel, H.A., 72, 85

Z
Zhang, D., 8
Zimmerman, B.J., 173–175, 177, 180, 183, 188
Zöllner, J., 48

Subject Index

A
Aims of education, 284
Antisemitism and the Enlightenment, 59–62
Argument
  aesthetic, 262
  utility/utilitarian, 262–265, 267, 268
Argumentation, 146, 151, 152, 173, 188, 243, 294
Asian science education, 6
Astrology, 5, 9, 12, 14, 34
Ataturk's reforms, 84
Atheism and Science, 294

C
CCK. *See* Cultural Content Knowledge (CCK)
Chinese Communist Party, and Feng Shui, 23–24
Chinese culture, modernization
  New Thought Movement, 21
Chinese science, historical features
  lack of experimental tradition, 18
Christianity and Islam, 69
Climate change, 101, 116, 263
Cognitive-epistemic system, 186
Compass, Chinese geomantic use of, 7
Concept definition
  operational, 125, 214, 225, 241, 242
Constructivism, 89, 90, 92, 105, 119–123, 222–224
Context of
  communication, 147
  discovery, 147, 237
  justification, 147
Controversial issues, 142, 157, 291, 292, 294
Counter-Enlightenment, 45, 52, 54, 59
Co-variance of changes, 248
Co-variation, 237
Creationism, 47, 53, 89, 112, 313
Cross-cultural learning, 289
Cultural Content Knowledge (CCK), 203, 204, 206–214, 217, 219, 221, 228, 229
Culture, knowledge as, 203–205, 207, 209, 211, 213, 215–218, 221–223, 225–227, 229
Culture of science, 289
Curriculum
  design of, 152, 168, 189, 205, 235–247, 250, 256, 257, 264
  development, 149, 235, 236, 240, 241

D
Definitions
  operational, 214, 225, 241–244, 251–253, 256
Demarcation problem, 27
Democracy, epistemic, 50–52, 57, 58
Dewey, John
  visit of Turkey, 83
Dialectics, 23, 24, 60
Discourses, 25, 68, 76, 86, 89, 90, 93, 102, 104, 105, 139–141, 145–150, 154, 158, 203, 204, 207, 212, 214, 215, 217, 222, 224, 225, 227–229, 236, 242, 252, 255, 256, 296

M.R. Matthews (ed.), *History, Philosophy and Science Teaching*, Science: Philosophy, History and Education, DOI 10.1007/978-3-319-62616-1

E

Energy, aspects of
- changes of, 238, 239, 243–255
- concept image of, 236, 248
- conservation law, 250, 254
- curriculum, 235–248, 251–256
- definition of, 254
- ibalance of, 250, 252
- increase/decrease of, 252
- literacy, 25
- measuring, 254
- simultaneous changes in, 250, 252, 254
- teaching of, 236, 251, 255, 256
- types/forms of, 252

Energy literacy, 25
Engineering education, 140–143, 148–159
Enlightened age versus age of enlightenment (Kant), 44, 48, 49, 54, 56–58
Enlightenment, the
- being enlightened, 45, 50–56, 64
- being unenlightened, 52, 55
- dates for, 44
- definitions of, 44
- and education, 6, 20, 23
- eight cardinal points of enlightenment, 59
- epidemiology of being enlightened, 53–56, 64
- and instrumental reasoning, 61, 63, 64
- as misleading abstraction, 43–60, 62–64
- modern detractors, 44
- and Nazism, 59–61
- and republicanism, 52, 55, 61, 63
- and science, 67, 69–83, 85–94
- and self-destruction, 62
- and terror, 59

Epidemiology of enlightenment beliefs, 22, 53
Epistemic
- cultures, 141, 142, 144, 148, 149, 158, 160
- practices, 140–142, 144–161
- subject, 140, 147, 148

Epistemic democracy, 50–52, 57, 58
Epistemology, 44, 50, 62, 81, 99, 110, 113, 115–117, 119, 121, 128, 129, 140, 143–145, 147–153, 160, 167, 168, 171, 176, 184, 203–206, 208, 209, 214, 215, 221–225, 227, 229, 240–242, 287, 292
Explanatory knowledge, 51
Explicit NOS instruction, 178–182, 184–186

F

Family Resemblance Approach, 169, 189, 208
Feng Shui
- architectural use, 11, 30
- astronomical problems, 19
- commercial practice, 3, 5
- energy teaching, and, 249
- hospitality industry, 9
- medical practice, 9
- origins of, 3, 12, 22
- personal practice, 9–10
- pseudoscience, as, 3, 4, 6, 27–33
- scientific testing of, 26–27

Fundamental theory, structure of, 209, 229

G

Genetically modified organisms (GMO), 155, 263, 265–267
Genetics
- history of, 151
- teaching, 151, 311–313

H

Hidden curriculum
- ideology, 86, 284
- indoctrination, 283, 285–287, 289–302
- Nature of Science, 283, 288, 292–295
- worldview, 289, 293

History of science (HS), 34, 209, 212–214, 221, 225, 237–239, 251, 252, 255–257
HPS&ST research tradition, 149, 203

I

Ideology and Science, 30, 33, 86, 100, 101, 292, 297–302
Image of science, 226, 240, 293, 299
Incommensurability-commensurability of scientific knowledge, 207
Indoctrination
- concept of, 28–286
- controversial, value based issues, 291, 292
- hidden curriculum, 283–289, 291–302
- intention, 285, 286, 295, 296, 301
- nature of science, 283, 284, 288, 292–295

Inquiry, 14, 16, 27, 29, 30, 52, 72, 99, 100, 102–109, 111–113, 115–121, 123–129, 132, 142, 144, 146–149, 151–156, 159–161, 168, 170, 171, 173, 177, 184, 186–188, 216, 226, 227, 239, 240, 273, 294, 310, 314
International Handbook of Research in History, Philosophy, and Science Teaching, 95, 134, 162–164, 191, 192, 230

J
Jesuit mission to China, 13

K
Kemalism, 83, 92

L
Literacy
  energy, 25
  evolution, 262, 265, 268–276
  scientific, 5, 123, 141, 146, 151, 154, 161, 210, 262–265, 268–271

M
Measurement
  operation of, 238
Mechanical equivalence, 237
Methodological individualism, 44
Modernism and Science, 103–123, 300
Multicultural education, 108

N
Nature of Science (NOS), 4, 6, 28, 34, 87, 100, 102, 103, 117, 143, 152, 153, 167–189, 206, 208, 216, 235, 267, 273, 283, 284, 288, 292–295, 297–302
Needham Question, 18
Newton's laws, 251

O
Objectivity-subjectivity of scientific knowledge, 203
Optical image, discipline-cultural account of, 216
Ottoman Empire
  Armenians in, 74, 78, 84
  18th century reforms in, 73–76
  19th century reforms in, 76–80
  co-education in, 80
  Darulfunun, 74, 77–80
  Greeks in, 56, 74, 78
  Jews in, 74, 216
  ordinance of general education, 78, 79
  schooling in late Ottoman, 77
  Tanzimat proclamations, 76, 77
  Tulip era, 73
  ulema, 68, 69, 71, 75, 77, 78, 80
Ottoman science, 71
Ottoman state, 69, 76

P
Periphery knowledge in cultural structure, 208, 211
Phenomena
  understanding of, 105, 146, 245, 261
Philosophy of education, 4, 284, 291, 295
Philosophy of science, 4, 6, 19, 28, 47–49, 90, 109, 139, 143, 147, 149, 203, 220, 221, 235–249, 251–256
Pluralism, 90, 92
Popper, third world of, 228
Positivism, 20, 70, 81, 87, 102, 298
Practical epistemology, 150, 153, 167
Presupposition, 294, 298, 299
Progressive Education Movement (USA), 307
Pseudoscience, characteristics of, 4

Q
Qigong, 4, 26
Quantitative relations
  between phenomena/processes, 237

R
Recapitulation of scientific accounts, 212
Reflective NOS instruction, 172, 173, 177–186, 188

S
Science
  curriculum, discipline-cultural organization of, 204, 206, 226
  education research, 172, 203, 235–249, 251–256, 284
  epistemology of, 150, 153
  history of, 34, 209, 212–214, 221, 237–244, 256, 257
  nature of, 4, 6, 28, 34, 87, 100, 102, 103, 117, 143, 152, 153, 167–189, 206, 208, 216, 235, 267, 273, 283, 284, 288, 292–295, 297–302
  philosophy of, 4, 6, 19, 28, 47–49, 90, 109, 139, 143, 147, 149, 203, 220, 236–243, 245, 247, 248, 250, 252–256
  as social system, 186
Scientific
  communities, 29–31, 33, 111, 113, 139, 140, 143, 287–289, 294, 302
  concepts and models, 287–291
  group, characteristics of, 29
  literacy, 5, 123, 141, 146, 151, 154, 161, 210, 262–265, 268–271

Scientific (*cont.*)
practices, 29, 139, 143, 145, 147, 169, 222
revolution, 18, 44, 47, 49, 62, 67, 72, 204, 206, 207, 309
revolution, discipline-cultural representation of, 67
theory, characteristics of, 29
Scientific Temper, in Indian Constitution, xiv
Scientism, 20, 67, 92, 118, 119, 125, 293, 294, 300
Self-regulated learning theory
adaptivity, 175, 177, 183, 184
attention focusing, 175, 176, 181
attribution, 175–177, 183, 185, 186
forethought, 174, 178
goal orientation, 175, 179
goal setting, 175, 176, 178, 179
metacognitive monitoring, 175, 182
performance, 174, 175
processes, 172, 174, 177, 179, 183
self-efficacy, 175, 176, 180
self-reaction, 175, 183, 185, 186
self-reflection, 174
task value, 176
Social and institutional structures, 284
Sociology of science, 140, 143–149, 226
Socio-scientific issues (SSI), 141, 142, 144, 151, 154–156, 158, 159, 161, 169, 291, 292
Students' interests, typology of, 180
Students' learning, representation of, 208, 209, 213
System
borders of, 106
isolated, 70

T
Taqii-al-Din, observatory of, 71
Teacher training, 84, 203
Temperature change, 237, 244, 250, 252
Tentativeness of scientific knowledge, 227
Theory-based structure of physics, 224
Theory-experiment dependence, 203
Theory-inquiry confusion, 227
Theory-laden experiment, 226, 227
Theory-law relationship, scientific knowledge of, 203
Tolerance, 47, 55, 70
Turkey
1960-1980, 92
1980-2010s, 88–91
creationism in, 89
German academics in, 83
Higher Education Council, 88, 89, 91
military coups in, 1960, 1971, 1980, 87, 88, 92
new state, 83
positivism in, 81, 87
post-modernism in Turkish education, 92
prayer leaders and preachers schools, 81
science education in, 67–69, 71–82, 84–92, 94
secularism in, 81, 92, 93
village institutes, 85, 86

U
Understanding, 4, 45, 68, 99, 140, 168, 195, 204, 235, 261, 283, 310

V
Views about science, 284, 297, 298, 301

W
Weight concept, in cultural perspective, 214
Worldview, 3, 5, 7–9, 13–21, 23, 29, 33, 67, 79, 103, 105, 113, 115, 284, 289, 293, 294, 296–302