

See discussions, stats, and author profiles for this publication at: <https://www.researchgate.net/publication/255989228>

A Conversation with Michael R. Matthews: The contribution of history and philosophy of science to science teaching and...

Article in Eurasia Journal of Mathematics, Science and Technology Education · November 2010

CITATIONS

5

READS

33

2 authors, including:



Yalcin Yalaki

Hacettepe University

23 PUBLICATIONS 22 CITATIONS

SEE PROFILE

Some of the authors of this publication are also working on these related projects:



Herkes İçin Kütüphane [View project](#)

A Conversation with Michael R. Matthews: The Contribution of History and Philosophy of Science to Science Teaching and Research

Yalçın Yalaki and Gültekin Çakmakçı
Hacettepe Üniversitesi, Ankara, TURKEY

Received 25 June 2010; accepted 19 October 2010

The following conversation with Michael R. Matthews took place in May and June of 2010 via e-mail after his visit to Istanbul and Ankara for giving seminars on “The Contribution of History and Philosophy of Science to Science Teaching and Research” at Bogazici University and Hacettepe University. Our conversation included topics such as Michael’s educational background, science teacher education in relation to history and philosophy of science, worldviews, nature of science, constructivism, possible future directions for research, and advices for junior scholars and doctoral students. We believe that Michael’s generous answers to our questions will be of interest to all science education researchers around the world.

Keywords: History and Philosophy of Science, Worldviews, Nature of Science, Features of Science, Constructivism, Science Teacher Education

YY&GC: You have degrees in different fields. How did you get interested in philosophy, philosophy and history of science and science education? Why did you choose to study all these fields instead of just one?

MRM: This is a long story, but I think it is worth filling out a little as the path into my last twenty-five years of concerns with ‘History, Philosophy and Science Teaching’ (HPS&ST) was not direct. [Something of my own life’s intellectual trajectory is told in my ‘A Fortunate Life: The Philosophical Formation of a Science Teacher’, available at the bottom of the Philosophy of Education Society of Australasia web page at <http://www.pesa.org.au/03mee.htm>.]

My interest in philosophy came from my education in a Roman Catholic high school where philosophy, at least Catholic philosophy, was frequently taught and occasionally discussed. Relatives and close family friends were priests, and a number of them had studied

philosophy in Rome and at Louvain, and one at Oxford. I believed that Philosophy was something that the Church was not only comfortable with, but had made a long and distinguished contribution to. Early in my teenage years I acquired a regular little Catholic library featuring authors such as Fulton Sheehan, Christopher Dawson, Martin D’Arcy, Barbara Ward and G.K. Chesterton; and Catholic philosophers such as Gilson, Maritain, Tresmontant and Copleston. I still have all of these books in my library.

So philosophy was something that I had some inkling of when in 1965, as a sixteen year old, I commenced my Science degree at the University of Sydney. In this degree, I studied Philosophy for two years. After graduating with a major in Geology, I completed a year of teacher training, (Diploma of Education, similar to English PGCE) at Sydney Teachers’ College. Along with science methods, physical education, and classroom practice, I completed a course in Philosophy of Education taught by Dr Anna Hogg, a Christian academic recently returned from studies with Richard Peters at the London Institute of Education. The standard class was compulsory for all DipEd students (probably 200), but Anna invited those five or

*Correspondence to: Gültekin Çakmakçı
Hacettepe Üniversitesi, Eğitim Fakültesi,
İlköğretim Bölümü, Beytepe, 06532 Ankara, TURKEY
E-mail: cakmakci@hacettepe.edu.tr*

six of us who had previous study of at least two years of philosophy into a sort of 'honours' class. The semester was spent reading Richard Peters' most important and just published *Ethics and Education* book (Peters, 1966).

The Philosophy of Education course was a 'Paul on the Damascus Road' experience. For the first time I was introduced to a coherent sense of the educational enterprise; an enterprise that should be marked by cognitive breadth and depth; something intimately linked to reasons, understanding and rationality; something directed to ethical ends and that was to be conducted in a moral manner. I became a champion of education thus conceived (what I would later see as old-fashioned Liberal Education), and have remained such. I came away from the course convinced that there is nothing so practical and useful for beginning teachers as a good introduction to philosophy of education. If teachers do not have a strong and defensible sense of why they are teaching and what they are aiming to achieve, then they are essentially rudderless or directionless in schools and can easily be blown around by every fad or political fancy.

Wanting to further study Philosophy of Education, in my first year of teaching, I enrolled part-time in a Master of Education degree at Sydney University. Bill Andersen was director of the philosophy programme; like Anna Hogg he was a Christian academic. After psychology training, he did a doctorate in analytic philosophy of education with Richard Peters and Paul Hirst at the London Institute. He brought the London School of philosophy of education to Sydney. He was a gentle, non-dogmatic, thoughtful teacher who in those years of the late 60s and early 70s encouraged an enormously enthusiastic, and one can probably say gifted, group of graduate students to apply themselves to philosophical issues in education. There was a core group of perhaps 10-15 students in the philosophy programme; all of us subsequently became professors of Education.

The clear message was that educational philosophy is best done in conjunction with straight philosophy. The examples of Israel Scheffler at Harvard, Richard Peters in London and Paul Hirst at Cambridge, and closer to home John Kleinig at Macquarie University and Paul Crittenden at Sydney University, were ample testament to the wisdom of this conjunction. These were all philosophers first, and this enabled them to make substantial contributions to educational studies and analysis. This message fitted well with my own prejudices, and having finished two years of philosophy in my Science degree, I decided to enrol in a double honour's degree in Philosophy and Psychology at Sydney University. This was done along with one subject per year in the Master's Philosophy of Education programme. All of this was being done whilst busy with school science teaching and numerous other school

engagements. Thereafter I have always believed that people in their 20s can learn so much if they have good and knowledgeable teachers who can inform and extend them; and that it is a crying shame to see students who are at their intellectual prime, having this precious time wasted by shallow teachers and programmes.

The Arts degree required two majors and I thought that Psychology would be a suitable for my second major and might possibly be of assistance in school teaching. Unfortunately my time as a student in the Psychology Department coincided with the high-water mark for Behaviourism in Australia, and the Sydney department had ridden this tide for some decades. The Professor, Richard Champion, used only half-jokingly say that: 'I would like to study humans, but what do they tell us about rats!'

The psychology honour's programme involved both a Theoretical and a Practical thesis. My theoretical thesis was a 200-page discourse on 'Causality, Intentions and the Explanation of Behaviour'. Its core was Hume's account of causation, and modern critiques of it, along with accounts of dispositional constructs.

The practical thesis was 'Bar Press Avoidance Learning in Rats'. This involved months and months of late-night rat running. My idea was to construct a situation where the rat by pressing the appropriate bar at the appropriate time, did not get shocked, but where the explanation could not be given without recourse to teleological or intentional constructs – these being *verboten* for behaviourism. Indeed to describe the behaviour as 'avoidance' was already seen as sliding down a dangerous mentalistic slope. The thesis was to be a sort of critique of behaviourism from within the cage, so to speak. There were 313 references. I mention references because the scholarly pattern then was to absorb yourself in what has previously been written in the field, and make some attempt to extend it. In contrast some in Education now refer to the 'dead weight' of literature reviews that impede fresh and original thinking. I cannot but think that this is a completely bizarre idea that is at odds with the very notion of scholarship.

What was clear to me in studying philosophy and psychology in parallel was how diminished was the latter by its failure to engage with the former. Psychological studies of Perception, Learning, Abnormal Psychology, Social Psychology, Cognition, Child Development - should all be done in conjunction with philosophy or at least informed by philosophy.

My Philosophy studies in the Arts degree began with third year of philosophy as I had completed second year in my Science degree. In 1972, Michael Devitt and Wallis Suchting offered the first ever course in an Australian philosophy department on 'Marxism and Philosophy'. I was one of the 40-50 students and university staff attending.



Figure 1: Yalçın Yalaki, Michael R. Matthews and Gültekin Çakmakçı in Ankara (from left to right).

The outstanding and lasting impact of my first year back in Philosophy was the honour's class on David Hume taught by Wallis Suchting. It was a methodical, diligently prepared, line-by-line, weekly study of Book One of Hume's *A Treatise of Human Nature* (Hume, 1739/1888). The philosophical lesson was the inadequacy of Empiricism as a theory of human knowledge and of the weakness of Hume's constant conjunction account of causality. But the lessons were only learnt after fourteen weeks of sweating blood. The message for students was that there should be no shortcuts in a philosophical argument, that rhetoric should not be substituted for analysis, and that the text of a serious philosopher should be accorded equally serious respect.

The fourth, or honour's year, seminar was on Philosophy of Science. Here too things had dramatically changed while I was away. In 1967 we were learning, in logical empiricist mode, about Ramsey sentences, how to write Carnapian reduction-sentences, and puzzling over the existential status of dispositional properties such as 'solubility'. In 1973, Kuhn's work had hit the Anglo world and the honour's seminar was a detailed reading of his *Structures of Scientific Revolutions* (Kuhn, 1970) along with the essays in the Imre Lakatos and Alan Musgrave collection *Criticism and the Growth of Knowledge* (Lakatos & Musgrave, 1970). While a good many scholars around the world were impressed with Kuhn, the Sydney philosophers had strong reservations about Kuhn's philosophical argument, and his historical account of the Galileo episode. They thought the philosophical arguments were poor, and at many places the historical account simply false. So I was somewhat taken aback and dismayed when twenty years later 'Kuhn-mania' swept through the international science education community (see Matthews, 2004).

My philosophy honour's thesis was not in philosophy of science, but on philosophical psychology. The thesis canvassed the then standard action/movement distinction that was widely elaborated in the literature; it then tried to provide a causal

interpretation of reasons. It was awarded first-class honours. I have not subsequently returned to this field.

In 1972, I was offered an appointment as a lecturer in Philosophy of Education at Sydney Teachers' College. It meant turning away from classroom teaching in schools to teaching at the tertiary level; from being a teacher to being an 'academic'. I very much enjoyed school teaching, which I had been doing along with all the foregoing studies, but the opportunity to work on the Sydney University campus, where the Teachers' College was located, and to be a short walk from the wonderful resources of Fisher Library, and to be close to the Philosophy and Education Departments, was irresistible.

Three years later, in 1975, I was offered, and accepted, a position as lecturer in Philosophy of Education at the University of New South Wales. I stayed at UNSW, with a furlough as Foundation Professor of Science Education in Auckland (1992-93), until my retirement in 2008, thereafter I have continued at the university as Visiting Research Fellow.

In 1978, on my first university sabbatical leave, I went to the Boston University Centre for the History and Philosophy of Science. This was a watershed year for me. The BU School of Philosophy, and the Centre, were then at their peak. The marvellous *Boston Studies* series was coming out; the Centre Colloquium was held each 6 weeks or so with stellar scholars presenting papers; the staff were outstanding and ranged over the complete spectrum of philosophical schools and positions – Marxists, Idealists, Phenomenologists, Personalists, Analysts, Whiteheadians, Existentialists, Logical Empiricists, and perhaps others. Michael Martin was a staff member. His book *Concepts of Science Education* (Martin, 1972) was one of the first full-scale philosophical treatments of central issues in science education.

I did one graduate course on Marxism with Robert Cohen and Marx Wartofsky. The course text was Robert Tucker *The Marx-Engels Reader* (Tucker, 1972). We just worked our way through a selection of the major texts. Both were impressive in their command of

philosophy and of Marx's work. Wartofsky was one of the luminaries of American philosophy; his masterful study of Feuerbach had just been published by Cambridge University Press (Wartofsky, 1977); regrettably his *Conceptual Foundations of Scientific Thought* (Wartofsky, 1968) had not been mentioned in Sydney University philosophy of science programmes.

My other graduate course was on Galileo with Abner Shimony, who like Cohen, was a joint appointment in Philosophy and Physics. Shimony was a PhD in physics and contributed original work to experimental quantum mechanics, specifically a monumental piece on the experimental test of Bell's Theorem; and he wrote original pieces on a range of foundational questions in physics. He also has a second PhD in philosophy from Yale. He is an outstanding academic (see for example Shimony, 1993). His semester course was simply a reading from front to back of Galileo's *Two Chief World Systems* (Galileo, 1633/1953) with philosophical commentary. To my shame, and perhaps also to the discredit of my Sydney University education, I had never to that time read a page of Galileo; we had read much about Galileo, but not Galileo himself.

Shimony's course was an eye-opener, and set me on a path of historical-philosophical investigating that I have followed to the present. The semester course manifested the value, if not necessity, of wedding philosophy to science and both to history of science. This was the pattern of 'BU Integration' so wonderfully displayed in volume after volume of the Cohen and Wartofsky edited *Boston Studies in the Philosophy of Science*. The Sydney Philosophy Department certainly defended science, but they did so as informed spectators, as readers of *Scientific American* or *Nature*; the philosophers of science at Boston University were both defenders of and participants in science. It was salutary to see in Boston how scholars of the highest calibre could hold hugely different positions, yet be respectful and cooperate in a collegial manner.

In reading the *Dialogue* I became intrigued by Galileo's pendulum experiments and began writing on this subject. On my return to Sydney I enrolled in an honours MA degree in order to write up in a more systematic way my newly acquired Galileo interests. The thesis topic was *The Natural/Violent Motion Distinction in Galilean Mechanics*; the degree was awarded in 1985. I wrote a number of articles on Galileo topics, one long book, with about 1,300 references (Matthews, 2000b), and edited, with Colin Gauld and Art Stinner, a pendulum-studies anthology (Matthews, Gauld & Stinner, 2005).

In 1987, I took sabbatical leave in the Philosophy Department at Florida State University. It was from here that my subsequent two-decade engagement in History, Philosophy and Science Teaching scholarship was launched. I went to Tallahassee because David

Gruender, who had written on Galileo was there, and because there were some capable philosophers, Jim McMillan and Many Shargel, in the Education Department.

The precise moment of launching of these past two decades work was when I returned in early 1987 from a large Washington conference to mark tri-centenary of publication of Newton's *Principia*. I casually remarked over coffee to Jaakko Hintikka, the FSU philosopher who was the editor of *Synthese* journal, that 'it is a great pity that science teachers do not attend such conferences as the Newton one. There was so much presented that would hugely interest them, and inform their teaching'. He suggested I guest edit a special issue of *Synthese* on the topic of 'History, Philosophy and Science Teaching'. I jumped at this wonderful opportunity. I began writing to a few individuals who I knew had an interest; they in turn recommended others, who recommended others. In the end I had about 60 excellent manuscripts from scholars all over the world. About ten could appear in *Synthese*, so rather than return the others I contacted journal editors I knew to see if they were interested in special issues of their journals on the topic. Among those responding positively was James Kaminsky, the editor of PESA's *Educational Philosophy and Theory* journal. As it turned out, this was the first of the five special issues to be published (Vol.20 No.2, 1988). Others were *Synthese* (Vol.80 No.1, 1989), *Interchange* (Vol.20 No.2, 1989, Vol.24 Nos.1-2, 1993), *Studies in Philosophy and Education* (Vol.10 No.1, 1990) and *Science Education* (Vol.75 No.1, 1991). Clearly the time was ripe for such a HPS&ST initiative.

David Gruender suggested seeking National Science Foundation funding to bring all contributors, and others, together for a conference on the subject at Florida State University. This application was successful, and working with Kenneth Tobin, an Australian newly appointed to a professorship of Science Education at FSU, the first HPS&ST conference was held in Tallahassee in November 1989. The conference marked the birth of the International History, Philosophy and Science Teaching Group, of which I was foundation secretary and Newsletter editor. The group's distinctiveness has always lay in bringing historians, philosophers, philosophers of education and science teachers together to investigate how historical and philosophical scholarship can inform theoretical, curricular and pedagogical problems that engage science teachers and administrators. With a couple of exceptions, this has always been done in a convivial and collegial manner.

Also during the 1987 sabbatical, in response to an invitation from Jay Hullett in Boston, the owner of Hackett Publishing Company and a former BU philosopher, I put together a small anthology of writings of the 'scientists' of the Scientific Revolution that had a

formative impact on the origins of modern European philosophy (Matthews, 1989). What I had learnt during my stay in Boston, and subsequently, is that the history of philosophy and the history of science go hand-in-hand; one should not be studied without the other. Unfortunately the philosophically important texts of the scientists ('natural philosophers' really) – Copernicus, Galileo, Newton, Boyle, Huygens, Descartes - were not readily available to philosophy students. In the twenty-two years since its first publication, the anthology *The Scientific Background to Modern Philosophy* has sold 34,000 copies. The sales indicate that a good many philosophy lecturers are in agreement that the teaching of early modern philosophy needs to recognise its intimate connection with early modern science.

What brought philosophy of education and science education together for me was a contract by Israel Scheffler in 1989 to write a book for his Routledge 'Philosophy of Education Research Library'. The title was *Science Teaching: The Role of History and Philosophy of Science*. I spent four years writing the book and it was published in 1994 (Matthews, 1994). As the first ever book with that title, it gave a brief history of efforts to engage HPS in science teaching; it pointed to contemporary theoretical issues engaging science teachers (constructivism, multiculturalism and religion); it indicated how curriculum and pedagogy in certain areas (air pressure and pendulum motion) might be better served by attention to the relevant HPS of the topics. Pleasingly the book is still selling sixteen years later.

What perhaps needs to be understood is that although I began teaching science in 1969, for the next 20 years I had no intellectual or academic involvement in science education; my further studies, research and sabbatical leaves were all in philosophy, philosophy of education and history and philosophy of science. My first science education conference was a National Association for Research in Science Teaching (NARST) conference in 1989. I was shocked. The conference was awash with half-baked, philosophically-silly, relativist and idealist Constructivism. I could not believe my ears. One plenary address was given by Ernst von Glasersfeld, and amid the cheering and foot-stomping I recall saying to the chap alongside me: 'This is pure Bishop Berkeley'.

I subsequently spent a long time documenting and reinforcing the correctness of this initial evaluation. I gave my first anti-constructivist paper at the US Philosophy of Education conference in 1992, modestly titled 'Old Wine in New Bottles: A Problem with Constructivist Epistemology' (Matthews 1992a). Denis Phillips, who was a former Australian science teacher and philosopher of education, then working at Stanford University, in his commentary on the paper said:

Mike Matthews has been too gentle on the constructivists. He recognizes that they commit philosophical blunders, but

nevertheless he charitably treats them as informed, competent, well-trained people who happen to hold a venerable philosophical position – classic empiricism. ... My own interpretation is less charitable' (Phillips 1992, p.314).

The same year a version of my anti-constructivist paper appeared in a widely distributed publication of the US National Science Teachers Association – *Scope, Sequence and Coordination: Relevant Research* (Matthews, 1992b). These papers were the seeds of my scholarly reputation as the *bête noire* of constructivism. This reputation was later fuelled by my edited anthology *Constructivism in Science Education: A Philosophical Examination* (Matthews, 1998) to which, among others, Wallis Suchting, Denis Phillips, Robert Nola and Peter Slezak contributed. This reputation was further enhanced (or blackened depending on one's point of view) by publication of another anti-constructivist article in the Denis Phillips edited, National Society for the Study of Education 2000 Yearbook (Matthews, 2000a). It is perhaps noteworthy that for the most part these early criticisms of constructivism were confined to its philosophical ambiguities, confusions and shortcomings; I did not much concern myself with its classroom efficacy, or its pedagogical outcomes. This concern came later.

YY&GC: During your career, how did your teaching of HPS change over the years? Why?

MRM: Yes, there has been a big change in how I have taught HPS to pre-service and in-service science teachers. When I was initially appointed to UNSW in 1975, I taught philosophy to undergraduate and postgraduate Science Education students. The classes were pretty much in the same vein, and covering the same material, of the classes I had taken as a student in HPS. My students in turn read Kuhn, Lakatos, Feyerabend; there were lectures on epistemology, on the rationality or irrationality of theory change, on scientific explanation, and so on. These courses did not work so well; students were like spectators at an intellectual tennis game between very impressive players. Kuhn served, Lakatos returned, Feyerabend volleyed, etc. Students watched, but they were not involved or engaged. After my 1978 sabbatical leave at the Boston University Centre for History and Philosophy of Science, my classes were different: they became not just HPS, but 'HPS for Science Teachers'. And they became historically based in some Scientific Revolution texts (mainly Galileo and Newton) and some Darwin texts (from the Norton Darwin anthology). Students recognised the names, and there was no resistance to reading the work of these famous scientists whose theories they were going to be teaching. The philosophy then came out of the texts being discussed. So instead of lectures on Realism this topic was developed by considering Newton's action-at-distance formulations;

instead of lectures on Idealisation this topic was developed by considering Galileo's pendulum studies; instead of lectures on Science and Ideology, this topic was developed by considering Darwin's eugenics recommendations, and so on (the course is described in Matthews, 1990). The general lesson I learnt was that when teaching HPS to trainee or actual science teachers, is that HPS should be grounded in curriculum material and personalities that they recognise and that they need to teach. One teacher said: 'We are hungry for this knowledge', that nicely sums up the matter.

YY&GC: I think I heard you saying, in science teacher education, it is better to teach HPS to prospective teachers rather than learning theories and teaching methods. Could you explain this further?

MRM: This is a complex matter. I believe, somewhat paradoxically, that the most practical thing for teachers is having a well-grounded philosophy of education; something that gives them direction for what they are doing with children and pupils; something that gives them some clarity about themselves as educators, and the intellectual and moral requirements of being an educator; and something that gives them an idea about the personal and social aims of education. Once things at this 'strategic' level are sorted out, then different questions at the 'tactical' level – about classroom teaching, assessment, curriculum, professional development - can be investigated and answered. But if you do not know where you are going, it is hard to work out how to get there. The first is a strategy matter; the second is a tactical matter.

In the last few decades teacher training courses have more or less abandoned strategic-level questions and formation. So-called 'foundation' courses – history, philosophy, sociology and even psychology – have been removed in favour of a wholesale emphasis on tactical-level courses dealing with teaching methods and, supposedly, children's learning. I do not deny that these tactical-level, applied, 'how-to' courses have some importance, but they are only as good as the content being taught. Teachers need to have an enthusiasm for and knowledge of science, and its role in the progress of society and culture, in order to inspire and motivate children to learn it; this type of 'higher-level' knowledge does not come from tactical-level courses on teaching method and classroom control techniques.

Seventy years ago Mortimer Adler argued for the same conception of the teacher, and warned against reducing teacher competence to mere 'know how' or pedagogical competence. In his 1939 *Reforming Education* he wrote:

For the most part, the members of the teaching profession are over-trained and undereducated. Teaching is an art and a teacher must be trained, but since the technique is one of communicating knowledge and inculcating discipline, it is not educational psychology and courses in method and

pedagogy that train a teacher, but the liberal arts ... Further, a teacher should have a cultivated mind, generally cultivated regardless of his field of special interest, for he must be a visible and moving representative of the cultural tradition to his students. But how can he be this if he has no acquaintance with the cultural heritage, if he cannot read well, and if he is not well-read? (Adler 1939/1988, p.79)

The value of history and philosophy of science (HPS) courses for trainee teachers is twofold: first, they contribute to the higher-order understanding and valuation of science which can be passed on to students; second they give teachers additional and enriching material to teach. Consider, for example, teaching pendulum motion. Tactical courses might assist a teacher to teach the well known formula $T = 2\pi(\ell/g)^{1/2}$ and get students to do suitable exercises in finding period for different lengths, or doing practical work to find g given T and ℓ . This is all standard and 'cookbook' physics. But if a teacher has done some rudimentary course on the history of pendulum motion studies then such a lesson or set of lessons can be transformed and students can learn about the role of the pendulum in timekeeping, in solving the Longitude Problem and thus enabling European dominance of trade and commerce, of ascertaining the shape of the earth, and of establishing international standards of length and mass. All of the latter can transform a routine classroom experience about pendulum motion into a most engaging and deeply informative understanding of science's contribution to society and culture. So given a choice between more lessons for trainee teachers on children's learning, or lessons on the history of pendulum motion study, I would opt for the latter. The former can be 'picked-up' on the job, the latter cannot be.

YY&GC: How would you define worldview?

MRM: Worldviews standardly are a composite of ontological, epistemological, anthropological, ethical and theological (including of course anti-theological) components. The Table 1 elaborates some of the typical questions that arise in each of these components.

These ideas are reflected in the definition of 'worldview' proffered by *The Cambridge Dictionary of Philosophy* where a worldview is said to be: 'an overall perspective on life that sums up what we know about the world, how we evaluate it emotionally, and how we respond to it volitionally'.

A significant part of a scientific worldview is the scientific *outlook*, or *habit of mind*, as the American Association for the Advancement of Science call it (AAAS, 1989). This has been called by Popper and others the *critical spirit*, a preparedness to put all questions on the table for serious and critical examination. This was the spirit of inquiry rekindled in

Table 1. Examples of Questions Asked in Different Worldview Components

| | |
|---------------------|--|
| Ontology | <ul style="list-style-type: none"> • What kinds of fundamental things exist in the world? (just matter? just mind? matter and mind? just natural or scientific objects? Scientific objects and spirits? Scientific objects, spirits and religious entities such as souls, angels, Gods?) • What kind of relations and interactions are possible between fundamental entities in the world? • Is the world purposive and teleological? • Is Providence operative in worldly processes? |
| Epistemology | <ul style="list-style-type: none"> • How do we know the world (by observation, experiment, intuition, or revelation)? • Can we identify better or more truthful views of the world among competing theories or research programmes? • What constitutes rationality or rational judgement? • What is the value or purpose of knowledge acquisition? • What is a scientific outlook or habit of mind? |
| Anthropology | <ul style="list-style-type: none"> • Is there something importantly distinctive about human beings (Reason? Conscience? Soul? Or are we just another species in the natural order?) • Is there something distinctive about our own race or tribe? (A chosen people? Descendants of a divine intervention? An eternally saved people? A naturally superior race?) • Is there something fundamentally distinctive about one gender? (Are males ordained to rule over women? Are women better endowed to understand nature and social life?) • What are the important components (rationality? creativity? spirituality? self esteem?) of human life that deserve cultivation? • Can human beings and human life be improved? Or is there some basic natural (selfish gene?) or religious impediment (original sin?) to human improvement? |
| Ethics | <ul style="list-style-type: none"> • Are there universal ethical norms? • How far into the animal realm, if at all, do ethical considerations extend? • Are ethical norms objective or entirely subjective? • What is the goal of ethical behaviour – maximising happiness? Being consistent with a natural moral order? Securing salvation? |
| Theology | <ul style="list-style-type: none"> • Does God, (or Gods), exist? • Has God entered into human history in any way or form? • Does God intervene in the workings of the world? • Has God made revelation or revelations to humans? • Are there sacred scriptures or holy books? • How is such revelation or scripture to be correctly interpreted? (Individually? By best scientific scholarship? By an authoritative church? By a teacher, priest or Imman?) • Can God be known independent of revelation such as by natural theology? |

the Western world with the Scientific Revolution, and codified and championed by the Enlightenment philosophers.

Western science, for example, grew out of a European medieval worldview dominated by Aristotelian philosophy and Christian belief and practice, but with the Scientific Revolution of the 17th century, science began to negate parts of this worldview of Christendom and to transform other parts. Islamic societies have their own history of coming to terms with the New Science and its associated worldview; sometimes science has been constrained and limited - for instance evolution cannot be taught in many Islamic states - and other times Islamic beliefs are adjusted. The same process of engagement between science and worldviews occurs in other cultures. (Matthews, 2009)

In the 1930s, R.G. Collingwood the Oxford philosopher wrote perceptively (once he jettisoned his earlier idealist commitments) on the historical interaction of science and worldviews. He opens his *The Idea of Nature* (Collingwood, 1945) with the claim that:

In the history of European thought there have been three periods of constructive cosmological thinking: three periods, that is to say, when the idea of nature has come into the focus of thought, become the subject of intense and protracted reflection, and consequently acquired new characteristics which in their turn have given a new aspect to the detailed science of nature that has been based upon it. (Collingwood 1945, p.1)

For Collingwood, central to science is a worldview about nature, an 'idea of nature'. He echoes what has been said above about the relation of science to philosophy when he goes on to say:

The detailed study of natural fact is commonly called natural science, or for short simply science; the reflection on principles, whether those of natural science or of any other department of thought or action, is commonly called philosophy. ... but the two things are so closely related that natural science cannot go on for long without philosophy beginning; and that philosophy reacts on the science out of which it has grown by giving it in future a new firmness and consistency arising out of the scientist's new consciousness of the principles on which he has been working. (Collingwood, 1945, p.2)

The three periods delineated by Collingwood, in which distinct ideas of nature hold sway and underlay the methods by which nature is investigated and the types of explanations of events and processes that are accepted, are: first the ancient Greek period, second the Renaissance, and third the Modern period. He says of the Greeks that:

Greek natural science was based on the principle that the world of nature is saturated or permeated by mind. Greek thinkers regarded the presence of mind in nature as the source of that regularity or orderliness in the natural world whose presence made a science of nature possible (Collingwood 1945, p.3).

This picture, of course, applies only after Aristotle's ascendancy over the pre-Socratic atomists, a point famously stressed by Karl Popper (Popper, 1963). Of the Renaissance period (16th and 17th centuries), he says that:

The central point ...was the denial that the world of nature, the world studied by physical science is an organism, and the assertion that it is devoid of both intelligence and life. ... The movements which it exhibits, and which the physicist investigates, are imposed upon it from without, and their regularity is due to "laws of nature" likewise imposed from without. (Collingwood, 1945, p.5)

Collingwood hints at, but does not explicitly coin the term 'mechanical worldview' for the Renaissance period.

Of the modern period, he says 'We are confronted not so much with a new cosmology as with a large number of cosmological experiments' (Collingwood, 1945, p.9). He sees Darwinian evolutionary theory as one of the principal scientific levers for rupturing Renaissance mechanical cosmology: 'It is impossible to describe one and the same thing in the same breath as a machine and as developing or evolving. Something which is developing may build itself machines, but it cannot be a machine' (Collingwood, 1945, p.14). Evolutionary science cannot be intelligently contained within the worldview that gave rise to it. A second such lever is Einstein's relativity theory because it makes the material world finite, bounded and closed on itself, not absolute and infinite as in the Newtonian and mechanical conceptions (Collingwood, 1945, p.152ff). Relativity alters our understanding of time and of space,

and thus the beginnings of time and the edge of space; thus our cosmology changes. For both evolution and relativity, Collingwood recognises that there have been successful and unsuccessful ways of philosophising about the scientific development; better and worse ways of articulating the new ontology and epistemology that are required by the science. He does, for instance, think that both Eddington and Jeans fail on this score because both give phenomenalist and subjectivist renderings of the required worldview (Collingwood, 1945, p.157). Susan Stebbing subsequently repeated this harsh judgement on both physicists (Stebbing, 1937/1958).

Having elaborated some of these examples of interconnection between science and philosophy, Collingwood takes the obvious next step and says:

For this reason it cannot be well that natural science should be assigned exclusively to one class of persons called scientists and philosophy to another class called philosophers. A man who has never reflected on the principles of his work has not achieved a grown-up man's attitude towards it; a scientist who has never philosophized about his science can never be more than a second-hand, imitative, journeyman scientist. (Collingwood, 1945, p.2)

YY&GC: What is the difference if any between worldviews, belief systems or value systems?

MRM: The important feature of worldviews is that they have ontological and epistemological components; value systems need not have these components, they can just be about ethical or moral considerations. If value systems are well thought out and carefully articulated they will have epistemological components; that is, they will have some stated view on *why* the ethical judgement is being made and how it can be justified. Ethical positions need not encompass ontological views about how the world is constituted and what entities and powers reside in the world. But as an ethical system becomes deeper and more articulated, it will inevitably begin to formulate ontological positions, and hence begin to take on some of the attributes of a fully-fledged worldview.

As an example, a person might initially have some moral or ethical view about cruelty to animals or the practice of killing and eating animals. This can be just at a judgemental or even intuitive level. When asked to justify their judgement or view, then some epistemological position might be formulated about the moral principle of promoting happiness, or at least not inflicting pain. But when asked for more justification, the person might begin articulating ontological views about animals and their status with respect to humans. Are particular animals, things that can be said to be happy or unhappy? Experience pain or not? Have a mind or be mindless? Have a soul or not have a soul? Concerning minds, emotions, reason and souls, are animals and humans simply on a continuum, or is there some abrupt ontological break between the animal

world and the human world? When a person addresses these questions, then their ethical position starts to become unearthed as really a worldview position. This is clearly seen in Descartes' celebrated account of animals as mechanistic automata, lacking consciousness, minds and certainly souls. This is the situation with respect to Hindu views about the evil of killing cows; cows are deemed to have a particular ontological status, they have something that distinguishes them from dogs, goats and other animals. Conversely, many have said that without God in one's ontology, then there can be no ultimately supportable moral system; if God does not exist, then anything goes as far as morals and behaviour are concerned. That is, there is a supposed link between ontology and ethics.

YY&GC: Does science has a definite, certain worldview?

MRM: Yes and No.

The scientific worldview has two complementary dimensions. First a view of the world - what it is and how it operates; and second an understanding of science and scientists such that the foregoing view of the world is possible and justified. That is, the scientific worldview is the combination of *what* is viewed (the object of science) and *how* this view is correctly established.

Both dimensions of the worldview of science have evolved over time: both its view of the world, and its understanding of what makes this view possible and justified have changed. That is, the ontological and epistemological commitments of science have changed over time.

The pre-Socratic philosophers - Democritus, Leucippus and Epicurus - were scientific materialists. For them, thunder was no longer Zeus growling in the heavens, it was the noise generated by streams of micro-particles (atoms) colliding in the upper reaches of the sky. This naturalistic worldview of early science (to speak loosely) was pushed aside by the rising tide of Aristotelianism from the fourth century BC. Until the seventeenth century European science [natural philosophy] was permeated by Aristotelian philosophy; by convictions about ontology, epistemology, ethics and theology that were informed by the texts of Aristotle as interpreted by the Roman Catholic Church. The Aristotelian-Scholastic view was things were constituted by form and by matter; and that the form of any body gave teleological direction to its development or movement. The world was analogous to an organism; processes, both organic and inorganic, were undergone to bring about some natural end state that fulfilled the nature of the entity being changed - the oak seed's development was always directed towards it becoming an oak tree. As one commentator said, in Aristotle's scheme, 'the present is pregnant with the future'.

With the Scientific Revolution this 'organic' picture of the world changed. All the major natural

philosophers of the seventeenth century - Galileo, Descartes, Boyle, Newton - rejected Aristotelianism in their scientific practice and in their enunciated philosophy. The new philosophy to which they turned reached back to pre-Socratic naturalism; it was corpuscularian, mechanical and realist - it has rightly been called the 'Mechanical World View'. In this new world view, there was simply no place for the entities that Aristotelianism utilised to explain events in the world: hylomorphism, immaterial substances, natures, substantial forms, teleology and final causes were all banished from the philosophical firmament.

For example, Galileo makes explicit his atomism, or corpuscularianism, when he says:

Those materials which produce heat in us and make us feel warmth, which are known by the general name of 'fire', would then be a multitude of minute particles having certain shapes and moving with certain velocities. Meeting with our bodies, they penetrate by means of their extreme subtlety, and their touch as felt by us when they pass through our substance is the sensation we call 'heat'. ... I do not believe that in addition to shape, number, motion, penetration, and touch there is any other quality in fire corresponding to 'heat'. (Galileo, 1623/1957, p.274)

Galileo's ontology was simply inconsistent with Scholastic metaphysics and thus with the medieval world view built upon it. Galileo's distinction between primary and secondary qualities was the beginning of the unravelling of this 'Medieval Synthesis' and its replacement by the 'Mechanical World View' and ultimately the 'Scientific World View'. This story is well told in the classic *The Mechanization of the World Picture* (Dijksterhuis, 1961/1986).

When the Enlightenment philosophers of the eighteenth century stressed the materialism, mechanism and determinism of the new science they brought upon themselves the ire of most contemporary religious figures who saw the emerging new worldview as anti-Christian and atheistic.

In the late nineteenth century and through the twentieth century, with the development of field theories of gravitation and electricity, the linking of science to ontological materialism or physicalism, was relaxed and the scientific worldview's ontology became naturalistic, meaning that the only kinds of entities deemed to exist in the world were those that science discovered as having causal engagements with processes that ultimately could be seen and recognised. Although the entities in the ontology of science changed over time, the basic principle remained constant: only entities recognised and utilised by science were deemed to exist. Naturalism ruled out any appeal to supernatural entities or influences in the explanation of events; only entities and powers recognised by science could be utilised in scientific explanations. Indeed 'supernatural' events were simply ruled out; all events were 'natural' events,

and in-principle capable of scientific explanation even if currently they seemed most baffling and incapable of being explained by contemporary science. Miracles are not recognised and are not allowed.

The Islamic tradition also decried the new scientific worldview, and its Enlightenment champions. A representative Islamic reaction to the Scientific Revolution can be seen when one contemporary scholar writes that the new science of Galileo and Newton had tragic consequences for the West because it marked:

The first occasion in human history when a human collectivity completely replaced the religious understanding of the order of nature for one that was not only nonreligious but that also challenged some of the most basic tenets of the religious perspective. (Nasr, 1996, p.130)

Nasr repeats Western religious and romantic laments about the new science when he writes:

Henceforth as long as only the quantitative face of nature was considered as real, and the new science was seen as the only science of nature, the religious meaning of the order of nature was irrelevant, at best an emotional and poetic response to 'matter in motion'. (Nasr, 1996, p.143)

This Islamic rejection of the spirit of the Scientific Revolution has recently been echoed by Prince Charles in a much-publicised and commented upon speech to the Islamic Studies Centre at Oxford University. In this speech on the Sustainability and Environmental Crisis, he said the crisis was the symptom of a much deeper malaise, namely the objectification of nature and the loss of soul.

It is common, and useful, to make a distinction between *ontological* naturalism and *methodological* naturalism. Ontological naturalism is what has just been described; it is the view that the only things that exist in the world are those things that best current science deems to exist and this in virtue of the things entering into regular causal relations with events and processes that ultimately are observable. This might be called a *hard* scientific ontology. Methodological naturalism is the view that whilst doing science, or while in the laboratory, one acts as if the world is as ontological naturalism describes; but this is only a tactical decision to enable science to be conducted. Outside the laboratory one can happily embrace a much richer ontology in which all sorts of entities and powers unrecognised by science can exist; an ontology where prayers can be listened to and be answered, where Gods and spirits can intervene, where souls exist, and so on. Most people are agreed that scientists must be at least methodological naturalists while they are engaging in the scientific enterprise of seeking causes and giving explanations. Many exemplary, prize-winning, scientists have in the past, and still today, been deeply religious. Nearly all the great scientists of the Scientific Revolution were Christian believers – Copernicus, Galileo, Boyle, Newton etc. The Director of the Human

Genome Project is a devout Christian. In the ranks of prominent scientists can be found devout Hindus, Muslims, Buddhists, Orthodox Jews, Sikhs, Mormons and all other forms of religious belief. These scientists are all methodological naturalists; they would not think of invoking religious or supernatural or spiritual causes in their *scientific* explanations of events or in their papers submitted for publication in research journals. Outside the laboratory they may believe in miracles, spirits, the efficacy of prayer, the existence of angels, and all manner and means of non-scientific entities and powers, but they do not invoke them inside the laboratory.

In brief, the scientific worldview can be characterised as:

(i) *Naturalism*. That is, the only entities and processes that can be appealed to in scientific explanations of events and phenomena are those entities and processes that science has established as entering into consistent causal relations. Naturalism can be either *methodological* (where non-scientifically established entities and powers can be held to exist, but they are not appealed to in science) or *ontological* (where only scientifically established entities and powers are believed to exist).

(ii) *Empiricism*. Sensory or empirical experience, mediated by reason, is the ultimate source and test of knowledge claims about the natural and social world. Human intuition and Divine revelation are disregarded as arbiters of knowledge claims about both human life and the world.

(iii) *Determinism*. The world is regular in its functioning; events occur, and only occur, due to the action of natural causes, and the same natural causes always have the same effects. This is the ontological basis for a related *Universalism* in epistemology; if a scientific description or explanation is true, then it is true for all; scientific truths are not culture, gender, class or ethnicity dependent.

(iv) *Experimentalism*. Knowledge comes from engagement with, and measurement of, the world; specifically experimentation and deliberate control of possible causal factors (variables). Passive observation is insufficient to gain knowledge of nature.

(v) *Communalism*. Knowledge is a public and communal product: the concepts people think with, the language they use, the technology they utilise, the tests they conduct – are all dependent upon a shared and social life. Scientific knowledge is created by individual scientists, but no scientist is an island. Science arises from communities, but some communities are more conducive to science than others. Ideally science requires an open society where ideas can be propounded and tested, where research can be freely conducted without ideological or political interference and control.

(vi) *Fallibilism*. Human knowledge is incomplete and fallible; our best scientific understandings are open to improvement. This is a lesson learnt from the history of

science itself; it is not just an *apriori* philosophical position.

(vii) *Criticism*. The scientific view of the world results from the open criticism of ideas, opinions and theories; thus having a critical outlook or 'habit of mind' is part of the scientific worldview. The scientific worldview does not allow for epistemologically privileged centres, either individuals or organisations. Nor does it recognise any body of claims as immune from, or 'off limits' to, criticism. Concerning knowledge of the world, there are no sages, prophets, cabals or revelations that are beyond or immune from criticism. The idea of sacred texts that should not or cannot be scientifically investigated is foreign to the scientific worldview. This is another lesson learned from the history of science; it is not just an *apriori* philosophical position.

The question of consistency between laboratory life and public life then arises, and there have been a number of well-formulated strategies for dealing with the apparent inconsistency. These amount to making either of the following four claims:

1. Science really has no metaphysics; that it makes no metaphysical claims that could then be counterposed to the metaphysical claims of religion. This is the option made famous by the Catholic positivist Pierre Duhem in his 1893 essay 'Physics and Metaphysics', and his 1911 letter to Father Bulliot (both in Ariew & Barker 1996).
2. The metaphysics of science is false; at least any such purported metaphysics that is inconsistent with religious beliefs. This is the option advocated by many Christian (Tresmontant 1965) and Islamic (Nasr 1996) theologians.
3. There can be parallel, equally valid, metaphysics. This is an old option given recent prominence by Stephen Gould in his NOMA formulation (Gould 1999).
4. There is fundamental disagreement about the metaphysics required by science, hence alternative metaphysical systems and beliefs can be freely entertained.

All these options have their problems, but this is not the place to elaborate them. As far as education is concerned, the important thing is to have students first recognise what are the options, and second carefully examine them and their implications and ideally take up a personal, if provisional, position on the matter. I have discussed these strategies in (Matthews, 2009).

YY&GC: Do you think scientific worldview should be accepted by all students?

MRM: I can give a three-level answer to this complex question.

At the minimal level, I think that the scientific worldview, or the components of science that have impacts on worldviews – namely epistemology, ontology, metaphysics, ethics – should be taught to all

students. It is a great failure of science education that so much time and energy is given over to teaching the facts, content and techniques of science – scientific *competence* we might say – that students learn little if anything about the bigger picture of science, especially its worldview dimension, and the history of its relations with other cultural and religious worldviews. Saying that the worldview components of science should be taught is not the same as saying the scientific worldview should be accepted. A teacher might wish it to be accepted, but acceptance or otherwise is a decision for students to make. No decent teacher wants to force or indoctrinate students into a scientific worldview.

At the second level, I think that those components of cultural or religious worldviews that science has shown to be wrong and mistaken should certainly be abandoned by students. This is perhaps easy to see in medical and health areas. It was once believed that the terrible scourge of small pox that periodically sentenced hundreds of thousands of people to horrible, lingering deaths – in 18th century Europe alone, 400,000 people a year were painfully killed by the disease – was caused by various spirits and for some, it was a sign of God's displeasure with the poor suffering individuals. When Edward Jenner in 1796 began successfully vaccinating children and adults with material from a cowpox lesion, he was widely opposed and criticised because he was frustrating God's will.

This opposition to Jenner was based in a worldview some components of which science has simply shown to be false and mistaken. Subsequently science has shown that the relevant 'material' in Jenner's vaccinations is vaccinia virus; this is what causes smallpox. Today it would be silly and completely irresponsible to go back to incantations and prayers as a way of preventing small pox; and it would be irrational accept the disease as as God's wish. We have outgrown this view of how the world (and God) works; we have passed beyond this frankly primitive worldview. Where there is this inconsistency between science and components of a worldview, students should simply accept the scientific story.

There are countless other such examples from medicine and health. Female genital mutilation is just one especially ugly and horrible example. The American Congress of Obstetricians and Gynaecologists estimates that currently more than 130 million women and girls have undergone some degree of this barbaric practice. For many, the justification is that cutting the young girl's genitals, specifically her clitoris, allows the resident evil spirits to leave with the blood flow. There is simply no scientific evidence for this belief, and an accumulation of contrary historical and anthropological evidence showing that it is a sham patriarchal mythology. Again, the belief and practice should be abandoned as being inconsistent with science.

Scientifically disproved beliefs regarding the supernatural, miracles, spirits, devil possession, magic, paranormal powers and other such things abound in society. A decade ago more than one-third of Americans polled in a large nation-wide study expressed belief in psychic powers, extrasensory perception (ESP), demonic possession, ghosts and telepathy (Gallup, 2001 at www.gallup.com). In a recent Pew poll in the USA it was shown that two-thirds of adults reported at least one of the following: personally communicating with the dead (29%), seeing or experiencing a ghost (18%), visiting a fortuneteller or psychic (15%), endorsing reincarnation (24%), believing in “spiritual energy” in physical entities, such as trees (26%), astrology (25%), or the “evil eye” (16%) (Pew 2009, at www.pew.com). Despite extensive efforts to find these phenomena and their non-scientific causes and powers, none have been found; science has provided no reason to believe in them, and in many cases overwhelming *naturalistic* or scientific explanations for the supposed supernatural phenomena and events have been found (see an excellent discussion, with references, in [Fishman, 2009](#)).

At this second level, I am saying that components of worldviews that science has shown to be false should be abandoned by students, at least by students who are wanting to be rational and thoughtful (if neither teachers or students want to be rational and thoughtful, then all bets are off; people can be as silly and bone-headed as they wish, but then the very exercise of asking and answering questions is pointless). But if enough supports are removed, or if absolutely central ones are removed, then the whole worldview edifice can crumble.

For many, this is the case with giving up belief in the special creation of species in the recent past, even if not exactly in 4004 BC as Bishop Ussher calculated in the seventeenth century. Belief in special creation is inconsistent with science, it has been proved false, and so should be abandoned. But abandoning it means having to change views about the interpretation of the Judaic-Christian-Islam scriptures (the holy books of the Abrahamic tradition), having to change beliefs about Divine Revelation, finding new accounts of the immortal soul and when it entered into human phylogeny, about Adam and Eve and the Fall and Redemption stories based upon them, etc. For some, these subsequent changes amount to the abandonment of the whole religious worldview that gave rise to the initial piece-by-piece conflicts with science. The situation is also the same for the countless, indeed nearly all, indigeneous cultures whose worldviews contain accounts of their people’s special and unique creation. For Melanesian people, as an example, nature is simply super-saturated with spirits: they inhabit trees, streams, cliffs, and exercise power over nature and people. Science has more or less established that none of these beliefs accord with facts; belief in this spirit-

laden world is simply false; and personally deleterious when matters of health and social welfare are predicated upon it. Antibiotics, not incantations, cure bacterial infections; ensuring clean water, not cleansing ceremonies or communal prayer, prevents the spread of cholera.

Recapping: at one level we clearly should teach about the worldview components of science; and at the next level we certainly should encourage students to abandon belief in worldview components that are inconsistent with science. So at the third level should we aim at and encourage students to accept the scientific worldview as outlined in points (1) to (7) above? My own answer is Yes.

YY&GC: What is the nature of science (NOS), and what aspects of NOS should be taught at schools (primary and secondary schools)?

MRM: There has been a long tradition of theoretical writing concerned with establishing the cultural, educational and scientific benefits of teaching about the nature of science, and of infusing epistemological considerations into science programmes and curriculum. Thomas Huxley and Ernst Mach last century (Huxley, 1885/1964; Mach, 1886/1986), then John Dewey (1910) and Fredrick William Westaway (1929) in the first decades of this century, began the tradition. This tradition was continued by the writings of Joseph Schwab and Gerald Holton in the ’forties and ’fifties (Schwab, 1949, 1958; Holton, 1952); the books of Leo Klopfer and James Robinson in the ’sixties (Klopfer, 1969; Robinson, 1968), the publications of Jim Rutherford, Gerald Holton, Robert S. Cohen and Michael Martin in the ’seventies (Rutherford, 1972; Holton, 1973; Cohen, 1975; Martin, 1972, 1974).

All of the foregoing writers were believed that science education would have a beneficial impact on the quality of culture and public life in virtue of students knowing some science subject matter, having some competence in, and appreciation of, scientific method, and internalising something of the scientific frame of mind. John Dewey well expressed this Enlightenment hope for science education when he said in his *Democracy and Education*:

Our predilection for premature acceptance and assertion, our aversion to suspended judgment, are signs that we tend naturally to cut short the process of testing. We are satisfied with superficial and immediate short-visioned applications. ... Science represents the safeguard of the race against these natural propensities and the evils which flow from them. ... It is artificial (an acquired art), not spontaneous; learned, not native. To this fact is due the unique, the invaluable place of science in education. (Dewey, 1916, p.189)

As I have indicated above in discussing the scientific worldview, the hopes of this Enlightenment tradition can only be realised if science is not taught in a way

narrow technocratic way; if teachers and curriculum writers aspire to conveying something of the nature of science to students and having them see the benefits and strengths of the scientific tradition.

Research and publications on NOS have mushroomed in the past two decades. My own book *Science Teaching: The Role of History and Philosophy of Science* (Matthews, 1994) surveyed the foregoing Enlightenment tradition, laid out some of its philosophical and educational achievements, and demarcated some avenues for NOS research. The work of Norman Lederman, professor of science education at the Chicago Institute of Technology, is familiar to many (see especially Lederman, 1992, 2004, 2007). His students have included Fouad Abd-El-Khalick, Renee Schwartz, Valarie Akerson and Randy Bell - all of whom have published widely in this field. Other prominent contributors to NOS research have been William McComas (1998) and Derek Hodson (2009).

The Lederman group's definition of NOS is characteristically catholic. They say that:

Typically, NOS refers to the epistemology and sociology of science, science as a way of knowing, or the values and beliefs inherent to scientific knowledge and its development. (Lederman, Abd-el-Khalick, Bell & Schwartz, 2002, p. 498)

The group maintains that 'no consensus presently exists among philosophers of science, historians of science, scientists, and science educators on a specific definition for NOS' (Lederman, 2004, p.303). Although recognising no across-the-board consensus on NOS, the group does claim that there is sufficient consensus on central matters for the purposes of NOS instruction in K-12 classes. The group has elaborated and defended seven elements of NOS that they believe fulfil the criteria of: (i) accessibility to school students, (ii) wide enough agreement among historians and philosophers, and (iii) being useful for citizens to know.

The elements – the 'Lederman Seven', one might call them - are:

1. The *empirical nature of science*, where they recognised that although empirical, scientists do not have direct access to most natural phenomena. It is claimed that 'Students should be able to distinguish between observation and inference... An understanding of the crucial distinction between observation and inference is a precursor to making sense of a multitude of inferential and theoretical entities and terms that inhabit the worlds of science' (Lederman et al., 2002, p.500).

2. *Scientific theories and laws*, where they hold that 'laws are descriptive statements of relationships among observable phenomena. ... Theories by contrast are inferred explanations for observed phenomena or regularities in those phenomena. ... Theories and laws are different kinds of knowledge and one does not become the other.' (Lederman et al., 2002, p.500).

3. The *creative and imaginative nature of scientific knowledge*, where they hold that 'science is empirical. ... Nonetheless, generating scientific knowledge also involves human imagination and creativity. Science ... is not a lifeless, entirely rational and orderly activity. ... scientific entities, such as atoms and species are functional theoretical models rather than copies of reality.' (Lederman et al., 2002, p.500).

4. The *theory-laden nature of scientific knowledge*, where it is held that 'Scientists' theoretical and disciplinary commitments, beliefs, prior knowledge, training, experiences, and expectations actually influence their work. All these background factors form a mindset that affects the problems scientists investigate and how they conduct their investigations.' (Lederman et al., 2002, p.501)

5. The *social and cultural embeddedness of scientific knowledge*, where it is held that 'Science as a human enterprise is practiced in the context of a larger culture and its practitioners are the product of that culture. Science, it follows, affects and is affected by the various elements and intellectual spheres of the culture in which it is embedded.' (Lederman et al., 2002, p.501)

6. The *myth of scientific method*, where it is held that 'There is no single scientific method that would guarantee the development of infallible knowledge ... and no single sequence of activities ... that will unerringly lead [scientists] to functional or valid solutions or answers.' (Lederman et al., 2002, p.502).

7. The *tentative nature of scientific knowledge*, where it is maintained that 'Scientific knowledge, although reliable and durable, is never absolute or certain. This knowledge, including facts, theories, and laws, is subject to change.' (Lederman et al., 2002, p.502).

This list has functioned widely in science education as a NOS checklist; it appears on classroom walls as the Seven NOS Commandments; and it informs the group's hugely popular VNOS (Views of Nature of Science) tests which are used in at least fifty published research papers to measure effectiveness of NOS teaching (Lederman, Schwartz, Abd-El-Khalick & Bell, 2001) and degrees of NOS understanding (Flick & Lederman, 2004, chap. IV; Schwartz & Lederman, 2008).

These seven items on the Lederman list need to be elaborated in much more detail before they can be really useful for teachers, students or curriculum writers. About each of the elements there is a long history of philosophical debate and refinement. The seven elements are better thought of as Features of Science (FOS) rather than Nature of Science items. But if they are Features of Science, then it needs to be argued why those seven features are picked out, and not other of the numerous features that can be said to characterise scientific endeavour and that also meet the three criteria of accessibility, consensus and usefulness.

Clearly many other things can be added to the FOS list, including those that have typically occupied philosophers of science when they turn to NOS questions. Among philosophers, NOS discussion and debate has traditionally revolved around epistemological, methodological, and ontological commitments of science. There has been long-standing inquiry in philosophy about the following matters (numbered as following on from the Lederman Seven, and with some representative literature cited), they are the staple of undergraduate philosophy of science programmes:

8. Demarcation. Are there demarcation criteria that separate science from non-science? Popper famously arguing for falsifiability as the hallmark of science (Popper, 1963, chap.11), while his opponents either modified this position such as Lakatos's 'methodology of research programmes' (Lakatos, 1970), or proposed other criteria such as Kuhn's 'puzzle solving' (Kuhn, 1970), or else denied that any such demarcation can be made (Feyerabend, 1970, 1975; Laudan, 1996).

9. Methodology. What is the, distinctive or otherwise, methodology of science? Inductivism, Hypothetico-Deductivism, Bayesianism, and other candidates have been variously championed (Nola & Sankey, 2000).

10. Explanation. What are the characteristics of proper scientific explanation? Initially Hempel and Oppenheim's deductive-nomological (D-N) or 'covering law' account was widely accepted (Hempel & Oppenheim, 1948), but this has been drastically criticised (Kitcher & Salmon, 1989), and the philosophical consensus is now joined on a causal account of explanation (Strevens, 2008).

11. Theory choice. Are there rational grounds for choice between competing theories in science or is theory choice or judgement an irrational one? (Radnitzky & Andersson, 1978).

12. Realism. Should scientific theories be interpreted in a realist (Rescher, 1987; Psillos, 1999) or an instrumentalist (van Fraassen 1980) manner? And, consequently, what is the ontological status of entities postulated by scientific theories? (Hempel, 1958; Maxwell, 1962).

13. Idealisation. What is the role, function and status of idealisation in scientific theorising? How are laws about idealised and contrary-to-fact conditions reconciled with claims that laws of nature are about the world? (Nowak, 1980).

14. Mathematisation. Is measurement and mathematics crucial to science? Many hold that the mathematisation of natural philosophy was the hallmark of early modern science. Galileo famously said in his *Assayer* that:

Philosophy is written in this grand book, the universe, which stands continually open to our gaze. But the book cannot be understood unless one first learns to comprehend the language and read the letters in which it is composed.

It is written in the language of mathematics, and its characters are triangles, circles, and other geometric figures without which it is humanly impossible to understand a single word of it; without these, one wanders about in a dark labyrinth. (Galileo, 1623/1957, p.237).

For Galileo, the objects in the world had to be represented mathematically in order for natural philosophy [science] to deal with them. Descartes took this project of mathematising physics even further; he wanted a unification of mathematics and physics (Gaukroger, 1980). Newton in the Preface to his *Principia*, the foundation stone of modern science, wrote that '... moderns, rejecting substantial forms and occult properties, have endeavoured to subject the phenomena of nature to the laws of mathematics. ... I offer this work as the mathematical principles of philosophy' (Newton, 1729/1934, p.xvii).

Given the dominating presence of mathematics in all branches of modern science, a clear question for teachers and students is just what role the mathematics plays in scientific understanding.

15. Values. What is the legitimate role of external social values in the selection of scientific research programmes? Do such external values have any role in the evaluation of scientific claims? (Lacey, 2005).

Given that science teachers are required by contemporary curricula and standards to teach NOS then the widely popular Lederman list is just the beginning of what can be taught; to the Lederman seven could be added any or all of the above features of science. A most useful position, similar to that outlined here is developed by Gürol Irzik and Robert Nola in their 'A Family Resemblance Approach to the Nature of Science for Science Education' (Irzik & Nola, 2011). But once any such list of features is enunciated, then the question arises of what is the purpose in teaching about the nature of science, or of explicitly introducing these features into science classrooms.

YY&GC: Generally speaking, researchers have used either an implicit or an explicit-reflective approach in their attempts to enhance students' and teachers' NOS views. What kind of instructional models do you think would be a more promising avenue to improve students and teachers' ideas about NOS?

MRM: I think we should use an explicit, but problematic or investigatory, model when teaching about Features of Science. I have expanded the Lederman Seven NOS tenets into fifteen features of science, but assuredly more could be added. Science is characterised by many interesting and engaging features. I do not want to replace the Lederman Seven with the Matthews Fifteen. So although we need to draw explicit attention to the features, we should do so by making them occasions for student investigation, reflection, discussion and debate. Philosophers debate over the meaning and significance of each item; where there

might be consensus at one level, at a deeper level there is divergence. Students should be encouraged to themselves philosophise about these features; to dig deep and see where they lead. The aim should be to have students interested in and engaged by these features of science; not for them to learn off a catechism list.

Naturally we like people to believe what we believe. Be it in politics, morals, religion, economics, environmental matters, or whatever else. Teachers have their share of this tendency. The problem for teachers arises when this natural tendency nullifies their role as educators. There is a thin, and sometimes difficult to delineate line, between education and indoctrination (see contributions to [Snook, 1972](#)).

For example, in the 1960s James T. Robinson, in what was perhaps the first ever education book with 'nature of science' in its title, provided an extensive and detailed account of the logical empiricist theory of science ([Robinson, 1968](#)). For Robinson, 'The challenge to science education is to bring to the full range of young people a comprehension of the nature of science as a humanistic enterprise' (Robinson, 1968, p. 12). In this goal he stood opposed to the dominant 'professional' approach to science education, which, particularly after the shock of *Sputnik*, stressed technique, specialisation, and frequently rote learning.

In pursuit of this goal he painstakingly spelt out 85 logical-empiricist theses about the nature of science and said that being scientifically literate required belief in each of these theses. We look back on his example and realise that there was something wrong. It is not just logical empiricist position that now seems flawed, but we think that something else was amiss, namely his conviction that his account of the nature of science defined scientific literacy; that his list should be learnt off. It was commendable that he produced a painstaking and detailed list of what he saw as the components of the nature of science, this is better than just soft-focus and vague generalities that amount to nothing, but his mistake was to turn this list into a catechism to be learnt. Rather he should have turned it into a list of questions for investigation and development (I have discussed this matter in [Matthews, 1997](#)).

This problem is still with us. For instance, a recent publication by two constructivists, Wolff-Michael Roth and Anita Roychoudhury, affirms that:

If the epistemological development is partly a factor of age, then we could simply wait for the students to become constructivists, the most mature epistemological commitment ... For us practitioners, this is not a satisfactory solution. However, simply exposing students to an environment in which a constructivist epistemology is implicit may not be sufficient ... Time should be provided

to discuss ... the plurality of languages for describing reality. (Roth & Roychoudhury, 1994, p. 28)

When this is done,

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

Their position is problematic. First, given that at least half of the philosophical establishment are not constructivists, it is presumptuous to assert that constructivism is 'the most mature epistemological commitment'. Second, and most importantly, the suggestion is made that teachers should aim to produce students in their own philosophical image. This has confused indoctrination with education.

YY&GC: What do constructivist approaches offer us for teaching science at schools?

MRM: Not much. What is educationally useful in constructivism is 'old hat', it has been known by good teachers ever since Socrates two-and-a-half thousand years ago questioned the slave boy about how to double the area of a given garden square. On the other hand, what is new in constructivism is deleterious to education and places completely unnecessary and distracting burdens on teachers. Constructivism is undoubtedly a major theoretical influence in contemporary science and mathematics education, and to varying degrees it has had curricular and pedagogical impact. Some would say Constructivism is *the* major influence in contemporary education. In its post-modernist and deconstructionist form, it is a significant influence in literary, artistic, history and religious education.

Constructivism has done a service to science and mathematics education: by alerting teachers to the function of prior learning and extant concepts in the process of learning new material, by stressing the importance of understanding as a goal of science instruction, by fostering pupil engagement in lessons, and other such progressive matters.

But liberal educationalists can rightly say that these are pedagogical commonplaces, the recognition of which goes back at least to Socrates. It is clear that the best of constructivist pedagogy can be had without constructivist epistemology – Socrates, Montaigne, Locke, Mill, and Russell are just some who have conjoined engaging, constructivist-like, pedagogy with non-constructivist epistemology.

Constructivism has also done a service by making educators aware of the human dimension of science: its fallibility, its connection to culture and interests, the place of convention in scientific theory, the historicity of concepts, the complex procedures of theory appraisal, and much else.

But again realist philosophers can rightly maintain that constructivism does not have a monopoly on these insights. They can be found in the work of thinkers as

diverse as Mach, Duhem, Bachelard, Popper, and Polanyi. These constructivist claims about science are only noteworthy for teachers who have read no history and philosophy of science; for teachers familiar with HPS then the claims are commonplace and hardly worth mentioning.

Some critics have been concerned that, despite all the promise, constructivism has yielded very little in the way of curriculum and pedagogical advice for teachers.

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

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

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

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

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

Indeed. Then after ten pages describing how the teacher tries to 'keep faith with students' reasoning ...

yet lead them to the intended learning goals' (p. 207), we are told that 'The process of investigating personal ideas and theories may lead students to reflect upon and question them. At the same time, it is unlikely to lead to the scientific view' (p. 218).

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

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

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

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

For soft, or pedagogical constructivists, who allow the transmission of knowledge, there is no theoretical problem about the teaching of science content; the problems are just pedagogical or pragmatic ones. Another contribution to the Monash seminar by Victorian school teachers (Anne Symons, Kate Brass and Susan Odgers) on teaching using constructivist ideas, illustrates some of these points. They say that traditional teaching of biology, specifically the body,

produces compartmentalised knowledge, ‘which does not give an overview of the functioning of the whole organism’ (Symons, Brass & Odgers, 1994, p.177). Traditionalists might say that the above problem can be solved by teaching a more comprehensive and integrated view of bodily systems; and does not necessitate the abandonment of traditional pedagogy, much less traditional epistemology. However the Victorian teachers wanted to introduce ‘a more effective teaching and learning process’ (p. 177), which meant giving the students a paper outline of the body and asking them to make and place cut-outs of internal organs on the drawing, and illustrate the connections between the organs. They were to have ‘responsibility for their own learning’ (p. 177). Although they were to have responsibility, nevertheless the teachers decided the subject for study, and determined that group work would be the *modus operandi*, with students being given a one lesson crash-course in group functioning (it is nice to see progressive teachers being authoritarian about the really important things). Then, ‘to get the students started they were told that the heart is approximately the same size as a fist’ (p. 180).

To the naive observer, there seems to be a lot of traditional teacher-directed pedagogy, and transmission of knowledge going on here; which is sensible, even if it violates hard constructivist tenets. If you tell a class that the heart is the same size as a fist, why not tell them that there is a left and right ventricle and so on? The limits appear not to be epistemological or theoretical, but just plain old pedagogical – what is going to work best for these kids, at this time, in this place, with these examination commitments? The Victorian’s lesson may have worked well. However there is no theoretical or pedagogical conclusion to be drawn from it. A group of Turkish constructivists recognise this point when in a recent publication surveying constructivist teaching practices they say: ‘lecturing may be an efficient method for learning if the goal is to present a large amount of information to large groups of high achievers’ (Uzuntiryaki, Boz & Kirbulut, 2010). But if this is the case, which it is, what then happens to the constructivist manta that ‘knowledge cannot be conveyed’?

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

How it is that a person himself ignorant of science is nevertheless able to ‘provide [learning] opportunities’ and reliably to ascertain that scientific ‘discoveries’ are in fact being made by his class is left unexplained in this article. But there cannot be many practising teachers who suppose that ignorance of anything is a qualification for teaching it. To teach something in ignorance of it is not just difficult: it is logically impossible. (Dearden, 1967, p. 143)

Pleasingly the ‘ignorance is bliss’ view was not shared by all contributors to the Monash seminar. Laurence Viennot and Sylvie Rozier, in their essay on teaching mechanics and thermodynamics, advise teachers that, when working with students’ ‘soft’ [naive] explanations, they should not ‘hide the dangers of a careless extension of such explanations to other cases’. They should, for instance, tell students that pressure-altitude relationships only hold if the ‘molecules have (more or less) the same velocity in the two compared cases’ (Viennot & Rozier, 1994, p. 252). This seems like a good old-fashioned case of the transmission of knowledge from someone who has it (the teacher), to someone who is wanting to get it (the student). Viennot and Rozier recognise that in teaching Newton’s third law ‘it is difficult to reach the more subtle level of vigilance without a very clear view about the physics at stake’ (p. 253). If content cannot be taught, and if teachers do not need to know the subject matter, then teacher process skills are substituted for content knowledge in constructivist classrooms.

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

For twenty years or more, I have written on the *philosophical* problems of constructivism, and some of these problems have been mentioned above, but in recent years the *pedagogical* problems of constructivist teaching (sometimes called ‘minimally-guided’, or ‘inquiry’, or ‘discovery’ teaching) have been documented by prominent educational researchers. Richard Mayer, a past-President of the Division of Educational Psychology of the American Psychological Association, a former editor of the *Educational Psychologist* and a former co-editor of *Instructional Science*, in something of a landmark study, reviewed an extensive body of research on constructivist pedagogy and concluded that it did not work, and where it did work, it worked in virtue of departing from constructivist principles (Mayer, 2004). His analysis was confirmed by Kirschner, Sweller and Clark who, in another review article, argued that:

... the past half century of research on this issue has provided overwhelming and unambiguous evidence that unguided or minimally guided learning is significantly less effective and efficient than guidance that is specifically designed to support the cognitive processing necessary for learning. Not only is minimally-guided learning ineffective for most learners, it may even be harmful for some ... The best evidence developed over the past half century supports the view that minimally-guided learning does not enhance student achievement any more than throwing a non-swimmer out of a boat in the middle of a deep lake supports learning to swim. (Kirschner, Sweller & Clark, 2006, p.75)

Such conclusions seem obvious, and dictated by the very nature of the discipline of science. Someone learning to play chess has to be told the rules by someone who knows the rules; learners cannot make up the rules, they cannot negotiate the rules, and even if they brainstorm to the conclusion that rooks can move diagonally, this does not mean that rooks can so move in a formal game of chess. Knowledge of what is allowed and not allowed in chess has to be *transmitted*; further competence in chess depends not just on knowing the rules, but on guidance and worked examples. So to in learning science.

YY&GC: What kind of instructional models would you suggest to teach science and the history and philosophy of science at schools? Are there any effective or ineffective instructional models?

MRM: I hesitate to advocate any particular instructional model. I think it is a mistake to believe that there are universal models, techniques, styles or methods of good teaching. What works for one age group may not work for another, what is effective in one culture might be ineffective or even a disaster in another, what promotes learning in one subject might inhibit learning in another subject, what one type of teacher might be comfortable with, might make another teacher with a different personality most uncomfortable and nervous. There is a universal law of gravitation, but there is no such universal law for good teaching.

For example, the 'questioning' method might be fine for some groups in some cultures, but it is altogether misplaced for other groups in other cultures. In Melanesian societies, and in numerous indigeneous cultures, it is not only inappropriate to directly ask questions of students (for fear of embarrassing them if they do not know the answer) but students are reluctant to ask questions of teachers for the very same reason. Some students are happy and cooperative about group work, others are not. Some students cope with open-ended inquiry, others require direction and guidance.

There is also a problem about what counts as effective and ineffective for any particular instructional model. For liberal education, success does not mean just getting the right answers, successful teaching in this

tradition means that students develop an understanding and appreciation of what is being taught. These goals guide my recommendations about teaching models. The goals for any instruction determine, or at least influence, desired teaching models at a *strategic* level; but at a *tactical* level there might be wide differences on classroom techniques and methods

At this strategic level, as I mentioned earlier in recounting changes in my own teaching of HPS to prospective and practicing teachers, the general lesson I learnt was that HPS should be grounded in curriculum material and personalities that teachers recognise and that they need to teach. One teacher said: 'We are hungry for this knowledge', that nicely sums up the matter.

Consider, for example, the Law of Inertia, the foundation stone of classical physics which is taught to every science student in school. It states that 'bodies either remain at rest or continue travelling in a straight line at a constant speed [velocity] unless acted upon by a force'. This is learnt by heart, and problems worked out using its associated formulae of $F = ma$. A purely technical science education might be satisfied with correct memorisation and mastery of the quantitative skills; these are the *strategic* objectives of most technical education, and constant drill, along with rewards and punishments, might be the appropriate *tactical* means to achieve these objectives. But just a little reflection on the law leads to fundamental issues of epistemology [we never see such behaviour in nature, nor can it be experimentally induced, so what is the source of our knowledge of it?], ontology [we do not see or experience such force apart from its manifestation, so does it have existence? What constitutes matter?], and cosmology [does such an inertial object go on forever in an infinite void? When and how did movement start?]. Thus reflection on inertia means an ascent from physics to metaphysics -there are countless philosophical discussions of inertia, one classic is Hanson (1965). Further an historical investigation of the precursors to the familiar Newtonian formulation of linear inertia, including Galileo's formulation of a law of circular inertia, reveals a good deal about the structure and mechanisms of the scientific enterprise, including the process of theory generation and theory choice - among numerous histories of inertia, a useful one with pedagogical import is Coelho (2007).

Philosophy does not have to be imported into science programmes or lessons, it is already there. Any science textbook will contain terms such as 'observation', 'evidence', 'fact', 'controlled experiment', 'scientific method', 'theory', 'hypothesis', 'theory choice', 'explanation', 'law', 'model', 'cause', etc. As soon as one begins to explicate the meaning of these terms, and related concepts, then philosophy has begun. And the more their meaning, and conditions for correct usage, is

investigated then the more sophisticated one's philosophising becomes. The pupil who asks: 'Miss, if no one has seen atoms, how come we are drawing pictures of them?' has put their finger on just one of the countless philosophical questions to which science gives rise (the relationship of models to reality). Likewise the student who wants to know whether after seeing twenty white swans they can conclude that 'all swans are white' touches upon another philosophical dispute (the problem of induction and evidential support for theory). And the student who wants to know after watching countless objects eventually come to a halt after being pushed whether they can conclude that 'all movement requires a mover', is engaged with other philosophical questions (the role of idealisation in formulation of scientific law and whether scientific laws apply to everyday behaviour of bodies). Similarly the student who, having been told about the force of gravitational attraction that exists between bodies, asks why we cannot see it, touch it, smell it, or trip over it, is highlighting yet another core philosophical issue (the realist versus instrumentalist debate about theoretical terms). (I have extended these points in Matthews, 1994, chap.5).

Science not only raises and is intertwined with the foregoing types of 'routine' philosophical questions, but these philosophical reflections lead inexorably to metaphysical ones, and finally to questions about worldviews. The phenomena and questions science investigates; the kinds of answers it entertains; the types of entities it recognises as having causal influence; the boundaries, if any, it sets to the domain of scientific investigation; and so on, all begin to touch upon or push against larger metaphysical commitments of an epistemological, ontological, and sometimes ethical kind. This ascent from studying nature (science) to philosophy to metaphysics is commonplace – hence, until the 20th century, the standard name for science was 'natural philosophy'. (I have extended these points in [Matthews, 2009](#).)

One proven way of integrating history and philosophy to the teaching and learning of science is to wed laboratory classes to historical stories; that is, to follow along the path of experimental science; to follow in the footsteps of the masters, as one might say. While doing this, it is possible to reproduce something of the intellectual puzzles and scientific debates that originally prompted the important experiments. Participation in this sort of journey can give students a much richer appreciation of the achievements, techniques, and intellectual structure of science, whilst developing their own scientific knowledge and competence. Students do not just read history of science, nor do they just do experiments or practical work; rather they combine history with experiment, and both with philosophical debate about the interpretation of experiments.

In recent times Nahum Kipnis has promoted this historical-experimental approach ([Kipnis, 1996, 1998](#)). He has, for example, based a course on Optics around retracing the classic, and usually very simple, experiments and demonstrations in the history of the subject ([Kipnis, 1992](#)). Students read original literature, they re-enact historical experiments, and then elaborate and debate interpretations of what they see in the laboratory. Readings and experiments on the restoration of air could suitably be substituted for the optics material. In such courses students do not just read history, they do practical work and carry out investigations; but instead of the practical activities being isolated, they are connected with a tradition of scientific development.

The foregoing might be seen as *strategic* advice for teachers; it suggests what to aim for in good liberal teaching of science. Translating it into practice, or classroom *tactics*, will depend upon all sorts of circumstances and I do not think there is any especially privileged universal method or model.

YY&GC: What do you think about the future direction of research in the field of history and philosophy of science?

MRM: I do not have strong ideas on this subject; HPS research will move according to its own dynamics. As far as educationally relevant studies are concerned, there is excellent work being done anew on Explanation that is of relevance to science teachers and education researchers who daily are working with the explanation of natural events and with the explanation of educational phenomena ([Strevens, 2008](#)). There is comparable historical and philosophical work on Objectivity in science that is of relevance to educators concerned with Feminism, Multiculturalism, Politics and Epistemology ([Daston & Galison, 2008](#)). Predictably, given the anniversary year, Darwinian studies have flowered ([Ruse & Richards, 2009](#)). And there is much else besides.

One area that I would like to see given more work and exposure, is the historical links between early modern science and the European Enlightenment, and the history of these links to the present time. One excellent study is by Timothy Ferris *The Science of Liberty* (Ferris, 2010). It is a commonplace now in science curriculum documents to stress the connection between science and culture, but it is much less common, indeed totally absent, to mention the greatest example of this connection: namely, the European Enlightenment and its immediate roots in the Scientific Revolution.

It is a scandal that the Enlightenment is denigrated in a number of Feminist, Multiculturalist and Constructivist-inspired science education circles. Better informed historical, philosophical and political reflection is needed to counteract these shallow attacks on what is one of the most important achievements of human

history, and moreover one that was consciously linked to science. Philosophers such as Abner Shimony (Shimony, 1997) and Mario Bunge (1999, chap.7) have contributed excellent analyses of Enlightenment arguments. Historians such as Johathan Israel (Israel, 2001) and Roy Porter (2000) have published comprehensive studies of the political, religious and philosophical dimensions of the Enlightenment. But more needs to be done; and most importantly this line of research should be attended to by science educators.

YY&GC: What would you suggest for junior scholars and doctoral students in terms of HPS research?

MRM: My advice here is very basic: students and young faculty need to do serious reading, thinking and study in the history and philosophy of science. Preferably this should involve formal course work in a university department; merely 'reading around' is not good enough. Defined reading, discussion, writing and correction as one gets in courses taught by a competent philosopher or historian, is most important for mastery of the field.

The importance of doing this basic study of one or more fields of HPS is depressingly well illustrated in Peter Fensham's recent book *Defining an Identity: The Evolution of Science Education as a Field of Research* (Fensham, 2004). The fifteen-chapter book is based on interviews with 79 leading science educators from 16 countries (48 being from the USA, Canada, Australia and Britain) and their responses to questions about their own major publications and the publications that influenced them. They were asked to respond to two questions:

Tell me about two of your publications in the field that you regard as significant.

Tell me about up to three publications by others that have had a major influence on your research work in the field.

Based on Fensham's interviews with the 'Who's Who' of science education research one can reasonably conclude that a good many of the research programmes in science education have suffered because researchers have either embraced or been badly influenced by mistaken philosophy. Further it is clear that researchers are not adequately prepared in the foundation disciplines that underwrite their research programmes – specifically learning theory (including cognitive science), and philosophy (especially the history and philosophy of science).

The interviews reveal that the overwhelming educational pattern for current researchers is: first an undergraduate science degree, followed by school teaching, then a doctoral degree in science education. As Fensham remarks 'Most researchers in science education have been teachers in schools, usually secondary ones, before their academic appointments'

(p.164). Most have no rigorous undergraduate training in psychology, sociology, history or philosophy.

Science education research is dominated by psychological, largely learning theory, concerns. Even here preparation of researchers is weak. Fensham writes that 'science educators borrow psychological theories of learning ... for example Bruner, Gagne and Piaget' (p.105). And he goes on to say, damningly, that 'The influence of these borrowings is better described as the lifting of slogan-like ideas from these theories' (p.105). The same, and even worse, happens in philosophy. The most striking example of this is the science education community's wholesale embrace of Kuhnian slogans about relativism, incommensurability, paradigm change and so on. The community became a cheer squad for Thomas Kuhn, but they kept cheering for him long after he abandoned his philosophical positions, at one point declaring he was 'not a Kuhnian' and that he 'regretted writing the purple passages'. Kuhn certainly reinforced a lot of constructivist-inspired relativism and subjectivism in the science education community. I have discussed this whole episode in Matthews (2004).

The lesson to be learnt here is the old lesson: the science education community should become more competent and professional in its engagement with HPS. But it needs to be recognised that it is hard for science educators to make up the shortfall in HPS training on the job. Peter Fensham draws attention to the 'considerable pressure to build a list of published work' (p.75) that affects the entire profession from top to bottom; it is the 'publish or perish' syndrome. This is an overriding reason why it is almost impossible for science educators to make up the shortfall in foundation training while on the job. The hot-house pressure induced by review and tenure committees means that very little time can be spent in the library, engaging in scholarship, or even in thinking. The demands to publish, to attend conferences, to engage in teacher development activities, to write grant proposals, and to develop new courses, are so great that finding time to carefully read a book such as Kuhn's *Scientific Revolutions*, much less to read the source material that it is built on (the texts of the Galilean revolution, for instance), or the critical literature that flowed from it - is nigh well impossible. Conference presentations, in-service courses, publications - can all appear on a CV or in an annual report. Books carefully read, or courses attended, do not appear on CVs and reports.

Some things that might mitigate the unfortunate situation are:

1. Instead of science teachers doing higher degrees in education (with a view to university appointment), encourage them first to do an undergraduate degree in an appropriate foundation discipline; after that do a PhD in Education. This is good for their personal

growth or education, and it is ultimately beneficial to whatever research programme they might engage in.

2. Ensure that PhD committees in science education have Foundations faculty on them. The participation of a psychology, philosophy or history researcher on thesis committees would contribute to raising candidate and supervisor awareness of past and current literature in the relevant disciplines.

3. Try as much as possible to ease publication pressure so that scholarship can be engaged in. This might amount to getting institutions to trade off quantity for quality in appraising a new staff member's output. Institutions should recognise that one substantial, long shelf-life publication contributes more to the field than ten or twenty or thirty second-rate, shallow, ill thought-out publications. The latter merely muddy the academic waters. Far better for science educators to spend a semester attending a philosophy, psychology or history course, and reading substantial books, than running around conducting yet another study of misconceptions or the impact of talking on class learning.

4. Encourage a system of joint appointments between Education and foundation disciplines. Encouragingly this happens to a small extent between Education and science disciplines, if other faculty could be cross-appointed to philosophy or HPS or psychology, this would assuredly lift the quality of scholarship and research in the field.

REFERENCES

- American Association for the Advancement of Science (1989). *Project 2061: Science for All Americans*. Washington, DC: AAAS
- Adler, M. J. (1939/1988). Reforming Education. In G. van Doren (Ed.), *New York: Macmillan*.
- Ariew, R. & Barker, P. (Eds.). (1996). *Pierre Duhem: Essays in the History and Philosophy of Science*. Indianapolis: Hackett Publishing Company.
- Bell, B. F. (1986). The Form 1-5 Science Review - Effecting Change, *New Zealand Science Teacher*, 48, 6-9.
- Bunge, M. (1999). *The Sociology-Philosophy Connection*. New Brunswick, NJ: Transaction Publishers.
- Coelho, R. L. (2007). The Law of Inertia: How Understanding its History can Improve Physics Teaching, *Science & Education*, 16(9-10), 955-974.
- Collingwood, R. G. (1945). *The Idea of Nature*. Oxford: Oxford University Press.
- Daston, L. & Galison, P. (2008) *Objectivity*. Brooklyn NY: Zone Books.
- Dearden, R. F. (1967). Instruction and Learning by Discovery. In R. S. Peters (Ed.), *The Concept of Education*, (pp. 135-155). London: Routledge & Kegan Paul.
- Dewey, J. (1910). Science as Subject-Matter and as Method. *Science*, 31, 121-127. Reproduced in *Science & Education*, 1995, 4(4), 391-398.
- Dewey, J. (1916). *Democracy and Education*. New York: Macmillan Company.
- Dijksterhuis, E. J. (1961/1986). *The Mechanization of the World Picture*. Princeton NJ: Princeton University Press.
- Duit, R. (1993). Research on Students' Conceptions: Developments and Trends. Paper presented at the Third International Conference on Misconceptions in Science and Mathematics Learning, New York, NY.
- Fensham, P. J. (1992). Science and Technology. In P.W. Jackson (Ed.), *Handbook of Research on Curriculum* (pp. 789-829). New York: Macmillan.
- Fensham, P. J. (2004) *Defining an Identity: The Evolution of Science Education as a Field of Research*. Dordrecht: Kluwer Academic Publishers.
- Fensham, P. J., Gunstone, R., & White, R. (Eds.). (1994). *The Content of Science: A Constructivist Approach to its Teaching and Learning*. London: Falmer Press.
- Ferris, T. (2010). *The Science of Liberty: Democracy, Reason, and the Laws of Nature*. New York: Harper-Collins.
- Feyerabend, P. K. (1970). Consolations for the Specialist. In I. Lakatos & A. Musgrave (Eds.), *Criticism and the Growth of Knowledge* (pp. 197-230). Cambridge: Cambridge University Press.
- Feyerabend, P. K. (1975). *Against Method*. London: New Left Books.
- Fishman, Y. I. (2009). Can Science Test Supernatural Worldviews?, *Science & Education*, 18(6-7), 813-837.
- Flick, L. B. & Lederman, N. G. (Eds.). (2004). *Scientific Inquiry and Nature of Science: Implications for Teaching, Learning and Teacher Education*. Dordrecht: Kluwer.
- Fraassen, B. C. van (1980). *The Scientific Image*. Oxford: Clarendon Press.
- Galileo, G. (1623/1957). *The Assayer*. In S. Drake (Ed.), *Discoveries and Opinions of Galileo* (pp. 229-280). New York: Doubleday.
- Galileo, G. (1633/1953). *Dialogue Concerning the Two Chief World Systems* (S. Drake Trans.), Berkeley: University of California Press. (Second revised edition, 1967)
- Gaukdroger, S. (1980). Descartes' Project for a Mathematical Physics. In S. Gaukroger (Ed.), *Descartes: Philosophy, Mathematics and Physics* (pp. 97-140). Brighton: Harvester Press.
- Gould, S. J. (1999). *Rock of Ages: Science and Religion in the Fullness of Life*. New York: Ballantine Books.
- Hanson, N. R. (1965). Newton's First Law: A Philosopher's Door into Natural Philosophy. In R. G. Colodny (Ed.), *Beyond the Edge of Certainty* (pp. 6-28). Englewood-Cliffs, NJ: Prentice Hall.
- Hempel, C. G. (1958). The Theoretician's Dilemma, *Minnesota Studies in the Philosophy of Science*, 2. (Reprinted from *Aspects of Scientific Explanation*, pp. 173-226 by C. G. Hempel, 1965, New York: Macmillan)
- Hempel, C. G. & Oppenheim, P. (1948). Studies in the Logic of Explanation. *Philosophy of Science* 15, 135-175. (Reprinted from *Aspects of Scientific Explanation*, pp. 245-290 by C. G. Hempel, 1965, New York: Macmillan)
- Hodson, D. (2009). *Teaching and Learning about Science: Language, Theories, Methods, History, Traditions and Values*. Rotterdam: Sense Publishers.
- Holton, G. (1952). *Introduction to Concepts and Theories in Physical Science*. Princeton: Princeton University Press. Second edition (revised with S. G. Brush) 1985, third edition *Physics the Human Adventure*, 2001.

- Holton, G. (1973). *Physics and Culture: Criteria for Curriculum Design and Modern Science and the Intellectual Tradition*. In G. Holton (Ed.), *Thematic Origins of Scientific Thought*. Cambridge: Harvard University Press.
- Hume, D. (1739/1888). *A Treatise of Human Nature: Being an Attempt to Introduce the Experimental Method of Reasoning into Moral Subjects*. Oxford: Clarendon Press.
- Huxley, T. H. (1885/1964). *Science and Education*. New York, The Citadel Press.
- Irzik, G. & Nola, R. (2011). A Family Resemblance Approach to the Nature of Science for Science Education. *Science & Education*, 20.
- Israel, J. (2001). *Radical Enlightenment: Philosophy and the Making of Modernity 1650-1750*. Oxford: Oxford University Press.
- Kipnis, N. (1992). *Rediscovering Optics*. Minneapolis MN: BENA Press.
- Kipnis, N. (1996). The "Historical-Investigative" Approach to Teaching Science. *Science & Education*, 5(3), 277-292.
- Kipnis, N. (1998). A History of Science Approach to the Nature of Science: Learning Science by Rediscovering It. In W. F. McComas (Ed.), *The Nature of Science in Science Education: Rationales and Strategies* (pp. 177-196), Dordrecht: Kluwer Academic Publishers.
- Kirschner, P., Sweller, J. & Clark, R. E. (2006). Why Minimally Guided Learning Does Not Work: An Analysis of the Failure of Discovery Learning, Problem-Based Learning, Experiential Learning and Inquiry-Based Learning. *Educational Psychologist*, 41(2), 75-96.
- Kitcher, P. & Salmon, W. C. (Eds.). (1989). *Scientific Explanation*. Minneapolis: University of Minnesota Press.
- Klopfer, L. E. (1969). *Case Histories and Science Education*. San Francisco: Wadsworth Publishing Company.
- Kuhn, T. S. (1970). *The Structure of Scientific Revolutions* (2nd edition). Chicago: Chicago University Press. (First edition, 1962).
- Lacey, H. (2005). *Values and Objectivity in Science*, Lanham MD: Lexington Books.
- Lakatos, I. & Musgrave, A. (Eds.). (1970). *Criticism and the Growth of Knowledge*. Cambridge: Cambridge University 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.
- Laudan, L. (1996). The Demise of the Demarcation Problem. In L. Laudan (Ed.), *Beyond Positivism and Relativism* (pp.210-222). Boulder, CO: Westview Press.
- Lederman, N. G. (1992). Students' and Teachers' Conceptions of the Nature of Science: A Review of the Research. *Journal of Research in Science Teaching*, 29(4), 331-359.
- Lederman, N. G. (2004). Syntax of Nature of Science within Inquiry and Science Instruction. In L. B. Flick & N. G. Lederman (Eds.), *Scientific Inquiry and Nature of Science* (pp. 301-317). Dordrecht: Kluwer Academic Publishers.
- Lederman, N. G. (2007). Nature of Science: Past, Present and Future. In S. K. Bell & N. G. Lederman (Eds.), *Handbook of Research on Science Education* (pp. 831-879). Mahwah NJ: Lawrence Erlbaum.
- Lederman, N., Abd-el-Khalick, F., Bell, R. L. & Schwartz, R. S. (2002). Views of Nature of Science Questionnaire: Towards Valid and Meaningful Assessment of Learners' Conceptions of the Nature of Science. *Journal of Research in Science Teaching*, 39, 497-521.
- Lederman, N. G., Schwartz, R. S., Abd-El-Khalick, F. & Bell, R. L. (2001). Preservice Teachers' Understanding and Teaching of the Nature of Science: An Interventionist Study. *The Canadian Journal of Science, Mathematics, and Technology Education*, 1(2), 135-160.
- Mach, E. (1886/1986). On Instruction in the Classics and the Sciences. In E. Mach (Ed.), *Popular Scientific Lectures* (pp. 338-374). La Salle: Open Court Publishing Company.
- Martin, M. (1972). *Concepts of Science Education: A Philosophical Analysis*. New York: Scott, Foresman & Co. (Reprint, University Press of America, 1985)
- Martin, M. (1974). The Relevance of Philosophy of Science for Science Education. *Boston Studies in Philosophy of Science*, 32, 293-300
- Matthews, M. R. (1989). *The Scientific Background to Modern Philosophy*, Indianapolis: Hackett Publishing Company.
- Matthews, M. R. (1990). History, Philosophy, and Science Teaching: What Can Be Done in an Undergraduate Course? *Studies in Philosophy and Education*, 10(1), 93-98.
- Matthews, M. R. (1998). *Constructivism and Science Education: A Philosophical Examination*. Dordrecht: Kluwer Academic Publishers.
- Matthews, M. R. (1992a). Old Wine in New Bottles: A Problem with Constructivist Epistemology. In H. Alexander (Ed.), *Philosophy of Education 1992* (pp. 303-311). Proceedings of the Forty-Eighth Annual Meeting of the Philosophy of Education Society. Urbana, IL: Philosophy of Education Society.
- Matthews, M. R. (1992b). Constructivism and the Empiricist Legacy. In M.K. Pearsall (Ed.) *Scope, Sequence and Coordination of Secondary School Science: Relevant Research* (pp. 183-196). Washington, DC: National Science Teachers Association.
- Matthews, M. R. (1994). *Science Teaching: The Role of History and Philosophy of Science*. New York: Routledge.
- 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. (2000). Constructivism in Science and Mathematics Education. In D.C. Phillips (Ed.) *National Society for the Study of Education 99th Yearbook* (pp. 161-192). Chicago: National Society for the Study of Education.
- Matthews, M. R. (2000). *Time for Science Education: How Teaching the History and Philosophy of Pendulum Motion can Contribute to Science Literacy*. New York: Kluwer Academic Publishers.
- Matthews, M. R. (2004). Thomas Kuhn and Science Education: What Lessons can be Learnt? *Science Education*, 88(1), 90-118.
- Matthews, M. R. (2009). Teaching the Philosophical and Worldview Dimension of Science. *Science & Education*, 18(6-7), 697-728.
- Matthews, M. R., Gauld, C. F. & Stinner, A. (Eds.). (2005). *The Pendulum: Scientific, Historical, Philosophical and Educational Perspectives*. Dordrecht: Springer.

- Maxwell, G. (1962). The Ontological Status of Theoretical Entities. *Minnesota Studies in Philosophy of Science*, 3, 3-27.
- Mayer, R. E. (2004). Should there be a Three-Strikes Rule Against Pure Discovery Learning? The Case for Guided Methods of Instruction. *American Psychologist*, 59(1), 14-19.
- McComas, W. F. (1998). *The Nature of Science in Science Education: Rationales and Strategies*. Dordrecht: Kluwer Academic Publishers.
- Nasr, S. H. (1996). *Religion and the Order of Nature*. Oxford: Oxford University Press.
- Newton, I. (1729/1934). *Mathematical Principles of Mathematical Philosophy*. Berkeley: University of California Press. (Translated A. Motte, revised F. Cajori)
- Nola, R. & Sankey, H. (2000). A Selective Survey of Theories of Scientific Method. In R. Nola & H. Sankey (Eds.), *After Popper, Kuhn and Feyerabend* (pp. 1-65). Dordrecht: Kluwer Academic Publishers.
- Nowak, L. (1980). *The Structure of Idealization*. Dordrecht: Reidel.
- Peters, R. S. (1966). *Ethics and Education*. London: George Allen and Unwin.
- Phillips, D.C. (1992). On Castigating Constructivists. In H. Alexander (Ed.), *Philosophy of Education 1992* (pp. 312-315). Proceedings of the Forty-Eighth Annual Meeting of the Philosophy of Education Society. Urbana, IL: Philosophy of Education Society.
- Pólya, G. (1977). *Mathematical Methods in Science*. Washington: Mathematical Association of America.
- Popper, K. R. (1963). *Conjectures and Refutations: The Growth of Scientific Knowledge*. London: Routledge & Kegan Paul.
- Porter, R. (2000). *The Enlightenment: Britain and the Creation of the Modern World*. London: Penguin Books.
- Psillos, S. (1999). *Scientific Realism: How Science Tracks Truth*. London: Routledge.
- Radnitzky, G. & Andersson, G. (Eds.). (1978). *Progress and Rationality in Science*. Dordrecht: Reidel.
- Rescher, N. (1987). *Scientific Realism: A Critical Reappraisal*. Dordrecht: Reidel.
- Robinson, J. T. (1968). *The Nature of Science and Science Teaching*. Belmont CA: Wadsworth.
- Roth, M-W. & Roychoudhury, A. (1994). Physics Students' Epistemologies and Views about Knowing and Learning. *Journal of Research in Science Teaching*, 31(1), 5-30.
- Ruse, M. & Richards, R. J. (Eds.). (2009). *The Cambridge Companion to the "Origin of Species"*. Cambridge: Cambridge University Press.
- Rutherford, F. J. (1972). A Humanistic Approach to Science Teaching. *National Association of Secondary School Principals Bulletin*, 56(361), 53-63.
- Schwab, J. J. (1949). The Nature of Scientific Knowledge as Related to Liberal Education. *Journal of General Education* 3, 245-266. (Reprinted in I. Westbury & N. J. Wilkof (Eds.), *Joseph J. Schwab: Science, Curriculum, and Liberal Education*, Chicago: University of Chicago Press, 1978).
- Schwab, J. J. (1958). The Teaching of Science as Inquiry. *Bulletin of Atomic Scientists*, 14, 374-379. (Reprinted in J. J. Schwab & P. F. Brandwein (Eds.), *The Teaching of Science*, Cambridge MA: Harvard University Press, 1960).
- Schwartz, R. & Lederman, N. (2008). What Scientists Say: Scientists' Views of Nature of Science and Relation to Science Context. *International Journal of Science Education*, 30 (6), 727-771.
- Scott, P., Asoko, H., Driver, R. & Emberton, J. (1994). Working from Children's Ideas: Planning and Teaching a Chemistry Topic from a Constructivist Perspective. In P. Fensham, R. Gunstone & R. White (Eds.), *The Content of Science: A Constructivist Approach to its Teaching and Learning* (pp. 201-220). London: Falmer Press.
- Shimony, A. (1993). *Search for a Naturalistic World View*. Cambridge: Cambridge University Press.
- Shimony, A. (1997). Some Historical and Philosophical Reflections on Science and Enlightenment. In L. Darden (Ed.), *Proceedings of the 1996 PSA Meeting* (pp. 1-14).
- Snook, I. A. (1972). *Concepts of Indoctrination*. London: Routledge & Kegan Paul.
- Solomon, J. (1994). The Rise and Fall of Constructivism. *Studies in Science Education*, 23, 1-19.
- Stebbing, L.S. (1937/1958). *Philosophy and the Physicists*. New York: Dover Publications.
- Strevens, M. (2008). *Depth: An Account of Scientific Explanation*. Cambridge MA: Harvard University Press.
- Symons, A., Brass, K. & Odgers, S. (1994). Year 9 Bodies'. In P. Fensham, R. Gunstone & R. White (Eds.), *The Content of Science* (pp. 177-184). London: Falmer Press.
- Tresmontant, C. (1965). *Christian Metaphysics*. New York: Sheed and Ward.
- Tucker, R. C. (1972). *The Marx-Engels Reader*. New York: W.W. Norton & Co.
- Uzuniriyaki, E., Boz, Y. & Kirbulut, D. (2010). Do Pre-service Chemistry Teachers Reflect their Beliefs about Constructivism in their Teaching Practices? *Research in Science Education*, 40(3), 403-424.
- Viennot, L. & Rozier, S. (1994). Pedagogical Outcomes of Research in Science Education: Examples in Mechanics and Thermodynamics. In P. Fensham, R. Gunstone and R. White (Eds.) *The Content of Science* (pp. 237-254). London: Falmer Press.
- Wartofsky, M. W. (1968). *Conceptual Foundations of Scientific Thought: An Introduction to the Philosophy of Science*. New York: Macmillan.
- Wartofsky, M. W. (1977). *Feuerbach*. Cambridge: Cambridge University Press.
- Yeany, R. H. (1991). A Unifying Theme in Science Education? *NARST News*, 33(2), 1-3.



The audio recording of this conversation/interview is available from the journal web site.

