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FOREWORD

History, philosophy, and science teaching: The new engagement

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Introduction

In 1986 a paper was published titled 'Science Education and Philosophy of Science: Twenty-five Years of Mutually Exclusive Development' (Duschl 1986). This was an account of the largely separate development of science education from the disciplines of history and philosophy of science. In the twenty years since the publication of Duschl's paper there has been a significant new engagement between these fields. Both the theory, and importantly the curriculum and practice of science education, is becoming more informed by the history and philosophy of science (HPS).

This engagement of HPS and science teaching is repeating the calls of early European Enlightenment figures such as Isaac Newton, John Locke and Joseph Priestley. The 18th century Enlightenment philosophers and educators (often they were the same figures) believed that a widespread understanding and appreciation of science would not only promote science, it would have positive flow-on effects for society and culture; if people thought and reasoned scientifically about politics, religion, ethics, law, history, social and cultural practices then much of the discord, persecution, wars and upheaval in society would be minimized. This was the Enlightenment hope: The spread of scientific thinking, or 'scientific habits of mind' as the AAAS has labeled it (AAAS 1989, chap.12), or 'scientific temper' as Nehru wrote into the Indian Constitution, would not only lead to knowledge of nature, but would improve social and cultural life.

At the beginning of the 21 st century, as in the 18 th century, there are contemporary crises and discord in world affairs – as evidenced in the Middle-East wars; the economic crises; the clashes within Christianity and Islam between modernizers and fundamentalists; the clashes between religions in countries like Indonesia, Pakistan, India and Ireland; the political struggles about democracy and human rights in countries such as China, Zimbabwe and Egypt; struggles over women's rights in countries such as Saudi Arabia, Iran and until recently European countries such as Spain and Ireland ; and intense struggles over free-speech in countries such as China and Russia. Aspects of all these clashes were to be found in 18 th century Europe, and the Enlightenment philosophers, inspired by the achievements of the 17 th century Scientific Revolution, thought that the new scientific method and outlook could be applied outside the laboratory to make headway in identifying and resolving the problems. Most of the Enlightenment philosophers strove for an open, critical, democratic society as they thought this was the only social arrangement in which science and the search for truth was possible. Of special concern was the application of the scientific method to the interpretation of Scripture and to the study of Church and religious history – on this latter point religious fundamentalists and progressives are still divided.

Accompanying these current social crises there is a well documented contemporary crisis in science education. The 18 th century did not have a science education crisis because, basically, there was no science education. Arguably, the first ever school science class was taught by Joseph Priestley at Nantwich, England, in 1758 (Schofield 1997, p.78). The education crisis is evidenced in the flight from the science classroom of both teachers and students, and in the appallingly high figures for science illiteracy.

The inclusion of HPS in science programmes does not, of course, guarantee solutions to these social and educational crises, but it can go some way toward their resolution. Thinking clearly and logically, seeking evidence for and against opinions, weighing alternative interpretations, trying to control variables in limited experiments, seeing examples of how great steps forward in knowledge of the world were made, and so on, may not solve current social and educational problems, but such scientific approaches can at least illuminate the problems and give students some experience in appraising beliefs and opinions, and give them some enthusiasm for the scientific tradition.

The inclusion of HPS dimensions in curricula and classrooms it can humanise the sciences and make them more connected with personal, ethical, cultural, and political concerns; it can make classrooms more challenging and thoughtful and thus enhance critical thinking skills; it can contribute to the fuller understanding of scientific subject matter - it can contribute a little to overcoming the `sea of meaninglessness' which one commentator said has engulfed science classrooms, where formula and equations are recited but few people know what they mean; it can improve teacher training by assisting the development of a richer and more authentic epistemology of science, that is a greater understanding of the structure of science and its place in the intellectual scheme of things. This last matter is the beginning of the sort of discipline understanding that Lee Schulman (1987) and before him Israel Scheffler (1970) have been urging teacher education programmes to promote.

Current Curricula Reforms

There are a number of elements in this contemporary engagement of HPS and science teaching. By far the most significant is the inclusion of history and philosophy of science components in various national school curricula.

The American Association for the Advancement of Science (AAAS) established in 1985 an extensive national study, Project 2061, to recommend an overhaul of school science. In 1989, after four years of deliberation and consultation, the project published its recommendations in a report titled *Science for All Americans* (AAAS 1989).

Science for All Americans contains 12 chapters giving the recommendations for school science of the National Council on Science and Technology Education. Chapter One is on 'The Nature of Science'. It includes discussions of objectivity, the mutability of science, the possible ways to demarcate science from pseudo-science, evidence and its relation to theory justification, scientific method, explanation and prediction, ethics, social policy, and the social organisation of science. The intention is that these themes be developed and discussed within science courses and that pupils completing school science know something of them; the intention is not that the topics be added to science courses and HPS be substituted for science content knowledge.
The introduction to Chapter Ten on 'Historical Perspectives' says: 'There are two principal reasons for including some knowledge of history among the recommendations. One reason is that generalizations about how the scientific enterprise operates would be empty without concrete examples.' It goes on to say that:'A second reason is that some episodes in the history of the scientific endeavour are of surpassing significance to our cultural heritage. Such episodes certainly include Galileo's role in changing our perception of our place in the universe'.

Following the AAAS report, in the USA the first ever National Science Education Standards were published by the National Research Council in 1996 (NRC 1996). They recognise the centrality of philosophical and historical knowledge in the teaching of science, maintaining for instance that students should learn how:

> science contributes to culture (NRC 1996, p. 21);
>
> Technology and science are closely related. A single problem has both scientific and technological aspects (NRC 1996, p. 24);
>
> curriculum will often integrate topics from different subject-matter areas … and from different school subjects – such as science and mathematics, science and language arts, or science and history (NRC 1996, p. 23);

scientific literacy also includes understanding the nature of science, the scientific enterprise, and the role of science in society and personal life (NRC 1996, p. 21);

effective teachers of science possess broad knowledge of all disciplines and a deep understanding of the disciplines they teach (NRC 1996, p. 60);

tracing the history of science can show how difficult it was for scientific innovators to break through the accepted ideas of their time to reach conclusions that we currently take for granted (NRC 1996, p. 171);

progress in science and technology can be affected by social issues and challenges (NRC 1996, p. 199);

if teachers of mathematics use scientific examples and methods, understanding in both disciplines will be enhanced (NRC 1996, p. 218).

These aspirations for science classrooms cannot be achieved without teachers who care about HPS and have some competence in it. A position paper of the US Association for the Education of Teachers in Science, the professional association of those who prepare science teachers, has recognised this in its own recommendation that:

> *Standard 1d*: The beginning science teacher educator should possess levels of understanding of the philosophy, sociology, and history of science exceeding that specified in the [US] reform documents. (Lederman et al. 1997, p. 236)

In the United Kingdom, a group of prominent science educators, reflecting on Britain's National Curriculum and the most appropriate form of science education for the new millennium, wrote a report with ten recommendations, the sixth of which said that: 'The science curriculum should provide young people with an understanding of some key-ideas-about science, that is, ideas about the ways in which reliable knowledge of the natural world has been, and is being, obtained' (Millar & Osborne 1998, p. 20). In elaborating this recommendation, the writers say that 'Pupils should also become familiar with stories about the development of important ideas in science which illustrate the following general ideas:

> * that scientific explanations 'go beyond' the available data and do not simply 'emerge' from it but involve creative insights (e.g. Lavoisier and Priestley's efforts to understand combustion);
>
> * that many scientific explanations are in the form of 'models' of what we think may be happening, on a level which is not directly observable;
>
> * that new ideas often meet opposition from other individuals and groups, sometimes because of wider social, political or religious commitments (e.g. Copernicus and Galileo and the Solar System);

> * that any reported scientific findings, or proposed explanations, must withstand critical scrutiny by other scientists working in the same field, before being accepted as scientific knowledge (e.g. Pasteur's work on immunisation). (Millar & Osborne 1998, pps. 21-22)

As well as curricula and pedagogy, the field of science education research clearly manifests this engagement of HPS with science teaching. This can be seen, for example, in the continued growth of the journal *Science & Education* which is subtitled: *Contributions from History, Philosophy and Sociology of Science and Education.* This is now in its 18th year of publication; details can be found at: www.kluweronline.com/issn/0926-7220. It is associated with the International History, Philosophy and Science Teaching Group that was formed in 1987, and has held large and successful biennial conferences since that time (see www.ihpst.org**).** In 2009, there were 48,650 article-downloads from the journal's web site, with 21% of the downloads coming from China (23% from the USA). The projected downloads for 2009 are 70,000. Given that the journal publishes just research related to the connection of 'history and philosophy of science with pedagogical, curricula, and theoretical issues in science education', these download figures indicate a huge research interest in the field of HPS and science teaching.

The range of connections between HPS and science education research can be seen in the titles of the thematic special issues of the journal that have been published. These include:

1994, 'Science and Culture', *Science & Education* **3**(1).

1995, 'Hermeneutics and Science Education', *Science & Education* **4**(2).

1996, 'Religion and Science Education', *Science & Education* **5**(2).

1997, 'Philosophy and Constructivism in Science Education', *Science & Education* **6**(1-2).

1997 'The Nature of Science and Science Education', *Science & Education* **6**(4).

1999, 'Values in Science and in Science Education', *Science & Education* **8**(1).

1999, 'Galileo and Science Education', *Science & Education* **8**(2).

1999, 'What is This Thing Called Science?', *Science & Education* **8**(4)

1999, 'Children's Theories and Scientific Theories', *Science & Education* **8**(5).

2000, 'Thomas Kuhn and Science Education', *Science & Education* **9**(1-2).

2000, 'Constructivism and Science Education', *Science & Education* **9**(6).

2003, 'History, Philosophy and the Teaching of Quantum Theory', *Science & Education* **12**(2-3)

2004, 'Science Education and Positivism: A Reevaluation', *Science & Education* **13**(1-2)

2004, 'Pendulum Motion: Historical, Methodological and Pedagogical Aspects', *Science & Education* **13**(1-2, 7-8)

2005, 'Science Education in Early Modern Europe', *Science & Education* **14**(3-4)

2006, 'Textbooks in the Scientific Periphery', **15**(7-8)

2007, ‘Models in Science and in Science Education’, **16**(7-8)

2008, ‘Social and Ethical Issues in Science Education’, **17**(8-9)

2008, ‘Feminist Philosophy and Science Education’, **17**(10)

2009, ‘Politics and Philosophy of Science’, **18**(2)

2009, ‘Constructing Scientific Understanding through Contextual Teaching’, **18**(5)

2009, ‘Science, Worldviews and Education’, **18**(6-7)

2010, ‘Darwinism and Education’, **19**(4-6)

(All articles in these thematic issues can be downloaded from the above journal web site.)

HPS and Teacher Education

Many have argued that HPS should be part of the education of science teachers - the British *Thomson Report* in 1918 had said 'some knowledge of the history and philosophy of science should form part of the intellectual equipment of every science teacher in a secondary school' (p.3).

Michael Polanyi made the obvious point that HPS should be as much a part of science education as literary and musical criticism is part of literary and musical education (Harré 1983, p.141). It would be odd to think of a good literature teacher who has no knowledge of the elements of literary criticism: of the tradition of debate over what identifies good literature, how literature is related to social interests, the history of literary forms etc. So also it should be equally odd to think of a good science teacher who has no reasonably sophisticated knowledge of the terms of their own discipline -'cause', 'law', 'explanation', 'model', 'theory', 'fact'; no knowledge of the often conflicting objectives of their own discipline - to describe, to control, to understand; or no knowledge of the cultural and historical dimensions of their own discipline. Israel Scheffler in a largely neglected paper of 1970 argued just this point. This is part of the difference between in being educated in science and being simply trained in science: teachers ought to be educated.

To advocate the importance of the history and philosophy of science for science teachers is not novel. The opening pages of a 1929 text for science teachers describes a successful science teacher as one who:

> knows his own subject ... is widely read in other branches of science ... knows how to teach ... is able to express himself lucidly ... is skilful in manipulation ... is resourceful both at the demonstration table and in the laboratory ... is a logician ... is something of a philosopher ... is so far an historian that he can sit down with a crowd of boys and talk to them about the personal equations, the lives, and the work of such geniuses as Galileo, Newton, Faraday and Darwin (Westaway 1929).

In the US, the Stanford-based, Carnegie-funded, National Teacher Assessment Project, directed by Lee Schulman, is the foremost teacher assessment programme. It is intellectualist in its criteria of teacher competence and rejects the behaviourist, managerial, measures of teacher competence so long enshrined in evaluation practice. Schulman asks about the 'missing paradigm' - the command of subject matter - and the ability to make it intelligible to students, abilities requiring the wider view provided by HPS. In one of his influential publications, Schulman has said:

> To think properly about content knowledge requires going beyond knowledge of the facts or concepts of a domain. It requires understanding the structures of the subject matter ... Teachers must not only be capable of defining for students the accepted truths in a domain. They must also be able to explain why a particular proposition is deemed warranted, why it is worth knowing, and how it relates to other propositions, both within the discipline and without, both in theory and in practice. (Schulman 1986, p.9).

To explain why a particular proposition is deemed warranted - the law of inertia, the principle of conservation of energy, the theory of evolution, continental drift theory, accounts of atomic structure etc. - requires knowing something about how evidence relates to theory appraisal, this is the standard business of epistemology. Schulman's ideas are reflected in the National Board for Professional Teaching Standards assessment guidelines - *What Teachers Should Know and be Able to Do* (1989).

Some Topical Questions

Robert Ennis in 1979 listed six areas of concern to science teachers that would benefit by philosophical attention. These were: scientific method, criteria for critical thinking about empirical statements, the structure of scientific disciplines, explanation, value judgements by scientists, and the development and writing of tests for scientific knowledge and understanding (Ennis 1979). These are perennial questions that engage science teachers and to which HPS can contribute (see Michael Martin’s early classic *Concepts of Science Education: A Philosophical Analysis* (Martin 1972)). Thirty-five years later there is point in up-dating this list. The additional topics I would propose are: Feminism, Constructivism, Ethics, Worldviews, Idealization, and Nature of Science (NOS). In one form or another, these issues and their implications have surfaced in science education debate.

(1) *Feminism* has provided strong challenges to the assumptions of both science teaching and of the philosophy of science. It is notorious that women, especially in Western countries, do not continue with scientific study, except for the biological sciences. There are many socio-cultural-economic-educational reasons put forward and debated for this withdrawal of women from the sciences. These are important, but largely empirical matters.

However in the past three decades Feminist philosophy has contributed to the debate by claiming that scientific method and epistemology is deformed by masculine assumptions and priorities, and hence inimical to women. One science educator, echoing this feminist position, wrote that girls' reluctance to pursue science is the result of science ‘being commonly portrayed as a discipline promoting objective, rational and analytic behaviour’ (Bell 1988, p. 159). Nancy Brickhouse, a prominent science educator, wrote that: “ Scientific knowledge, like other forms of knowledge, is gendered. Science cannot produce cultural or gender-neutral knowledge…” (Brickhouse 2001).

These arguments may have some initial appeal, but they are fraught with problems. They are historical and philosophical claims that need to be defended, not just asserted; and further their defense is questionable. We are seldom told why objectivity, rationality and analytic thinking are bad. This is precisely the type of thinking that the Enlightenment championed, and one might have thought that such traits were desirable, and sorely needed in the social and political arena.

Furthermore, many women reject the claim that objectivity, rationality and analytic thinking are alien to them. Norette Koertge, a prominent philosopher of science and one of the first philosophers to write on science education (Koertge 1969), maintains against certain feminists that:

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

Another woman, also a philosopher of science, has written that:

> Viewed by a philosopher of science, there is nothing short of a puzzle as to why, at this date, any group of science educators would invoke so patently flawed a philosophical position as ‘epistemologies of feminism’, in the hope that women in science will then benefit from a revamped theory of learning that is modeled on or guided by its flawed theoretical notions. It is time that science educators are told, bluntly, the conclusion which philosophers of science have reached after two decades or so of careful, and even hopeful, consideration of feminist standpoint theory. The conclusion, in brief, is that feminist standpoint theory is indefensible. (Pinnick 2007, p.1056)

As much as need be said here is that feminist epistemology is widely accepted among science education researchers; and it is thought that its adoption will assist both in reforming science and bringing girls into science classrooms. But these claims rest on very debatable historical and philosophical positions. Hence more informed and sophisticated HPS knowledge is requisite for understanding in this field. (See contributions to the special issue of *Science & Education* on the subject (2008, vol.17, no.10)

(2) *Constructivism* is arguably the dominant epistemology among science educators. One recent commentary has identified the following schools or variants of constructivism: contextual, dialectical, empirical, information-processing, methodological, moderate, Piagetian, postepistemological, pragmatic, radical, realist, social and socio-historical; to which can be added, humanistic (Cheung & Taylor 1991).

There are a host of philosophical issues in constructivist theory that deserve elaboration: What account of the social dimension of knowledge is given?, What are the criteria for the adequacy of student conceptions: are they judged against norms of the scientific community, or against other student accounts, or against the individuals' prior conceptions?, Is there a confusion of successful pedagogical practice with epistemological claims? Driver in one publication recognises an essential tension in constructivist practice: that between getting students to construct and make meaningful their own accounts of something and getting them to participate in a scientific community that has its own theory and understandings (Driver & Oldham 1986). The former makes no epistemological judgement, it only refers to psychological mechanisms; the latter does make epistemological judgements. Teachers who are concerned with students entering and mastering this sphere of public knowledge will standardly need to indicate that explanations that students might devise and feel content with are in fact inadequate.

Many writers, myself included (Matthews 1993, 2000b), believe that there are serious philosophical flaws with constructivism: The first is its idealist ontology which is inconsistent with the practice of science; the second is its relativist epistemology, which is inconsistent with the growth of science. Constructivist teachers do a disservice to students, and to culture more broadly, by promoting such flawed philosophy in their classes. The prominent science education, John Staver, clearly stated the idealist position:

> …For constructivists, observations, objects, events, data, laws, and theory do not exist independently of observers. The lawful and certain nature of natural phenomena are properties of us, those who describe, not of nature, that is described. (Staver 1998, p.503)

The flaws in this claim should be obvious: Observations clearly depend upon us, but not the objects observed, nor their structures.

Equally clearly, Grayson Wheatley states the relativist epistemology of constructivism as follows:

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

His principle one is not controversial; his principle two, relativism, is highly controversial among philosophers.

The relativist position leads eventually to the abandonment of Truth itself. This is recognized by two science educators who are not embarrassed to assert that researchers and teachers need to find ways how to:

> deprivilege science in education and to free our children from the "regime of truth" that prevents them from learning to apply the current cornucopia of simultaneous but different forms of human knowledge (Van Eijck & Roth W.-M.2007, p.944)

This is a truly remarkable claim for science educators to make, especially as one of them is a much rewarded, much cited and influential figure in the field.

Again, for current purposes one need not follow through these philosophical debates, it suffices to recognize that constructivism gives rise to them and that some knowledge of HPS is essential for intelligent and informed discussion of the matters. Much in education and in society hinges on getting the philosophy correct in these matters. The ontological idealism, relativism, and subjectivism of constructivism is particularly ill-suited to deal with the complex, trans-social problems facing the contemporary world. There is a need for the sustained application of reason and the rejection of self-interest in the attempt to deal with pressing environmental, political and social questions -- think of the political situation in Africa or the Balkans. Karl Popper recognised this socially corrosive aspect of constructivism, when he said:

> The belief of a liberal -- the belief in the possibility of a rule of law, of equal justice, of fundamental rights, and a free society -- can easily survive the recognition that judges are not omniscient and may make mistakes about facts. . . . But the belief in the possibility of a rule of law, of justice, and of freedom, can hardly survive the acceptance of an epistemology which teaches that there are no objective facts; not merely in this particular case, but in any other case. (Popper 1963, p.5)

(3) *Worldview* issues naturally emerge from the subject matter of science: Einstein spoke of the scientist being a philosopher in workingman's clothes. Many have written on the inextricable connection between science and metaphysics (for example, DeWitt 2004). If science has developed as a dialogue with metaphysics (to say nothing of interjections from the political, economic and social realms), then to teach science as a soliloquy in which science just talks to itself and grows entirely by self-criticism is to impoverish the subject matter.

I have recently edited an anthology titled *Science, Worldviews and Education* (Matthews 2009a) in which scientists, philosophers, theologians, historians and educators take up fundamental questions such as:

- What constitutes a worldview?
- How do worldviews impinge upon and in turn be modified by ontological, epistemological, ethical and religious commitments?
- What worldview commitments, if any, are presupposed in the practice of science?
- What is the overlap between learning about the nature of science (NOS) and learning about worldviews associated with science?
- What is the legitimate domain of the scientific method? Should scientific method be applied to historical questions, especially to historical questions concerning scriptures and sacred texts?
- To what extent should learning about the scientific worldview be a part of science instruction?
- Should science instruction inform student worldviews or leave them untouched?
- What judgement do we make of science education programmes where the scientific view of the world is not affirmed or internalised, but only learnt for instrumental or examination purposes; where learning science is akin to an anthropological study?
- What judgement do we make of proposals that students should become just ‘border crossers’ moving from their own culture with its particular worldviews to the science classroom in order to ‘pick up’ instrumental or technical knowledge and then back to their ‘native’ culture without being affected by the worldviews and outlooks of science? This is the anti-Enlightenment idea that science should leave culture untouched.

Science teachers have an interest and concern with all of these questions and, again, it is clear that their informed discussion requires familiarity with the history and philosophy of science.

(4) *Idealization* is the sine qua non of modern mathematical science, yet it is very little understood by teachers, it rarely occurs in textbook accounts of the scientific method, and is often ignored by

philosophers who conduct discussion of induction, falsification, and the testing of theory completely oblivious to the fact that it is idealized laws and theories that are being discussed, and simple logic is inappropriate to their evaluation (see Matthews 2000a, chap.10). Also much science education literature on concept acquisition proceeds in an Aristotelian manner, in which idealizations are treated as empirical generalisations. Clearly the acquisition of the concept of point mass, frictionless surface, inertial frame, elastic collision, rigid body, etc. does not occur in the Aristotelian manner, they do not arise from looking at bodies and inducing common features. Galilean/Newtonian idealization was a monumental conceptual achievement, arguably something that separates human thought from all animal cognition. This achievement must be imparted to students - they will not acquire the idealisations by looking at nature.

(5) *Nature of Science* (NOS). Many individuals and groups in science education have researched factors impinging on the teaching and learning of NOS: What is taught? How it is taught? What is learned? How it is best learnt? Etc. This research has done much, but suffers because of 'soft focus' and ambiguous writing at critical points where important philosophical issues are at play.

One important group of NOS researchers has been the 'Lederman' group that 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 fulfill 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 seven features of science, or NOS elements – the 'Lederman Seven', if one might so call the list clearly needs to be much more refined and developed in order to be useful. This is not just the obvious point that when seven matters of considerable philosophical subtlety, and with long traditions of debate behind them, are dealt with in a few pages, then they will need to be further elaborated, rather it is the more serious claim that at crucial points there is ambiguity that mitigates the list's usefulness as curricular objectives, assessment criteria, and as goals of science teacher education courses.

For instance consider the first item on the list. In discussing the empirical nature of science, it is maintained that there is wide enough agreement on the 'existence of an objective reality, for example, as compared to phenomenal realities' (Lederman 2004, p.303). This is quite so, but the serious debate among philosophers is not the reality of the world, but the reality of explanatory entities proposed in scientific theories. This debate between realists on the one hand, and empiricists or instrumentalists on the other has gone on since Aristotle's time.

Aristotle maintained that the crystalline spheres in which the planets were supposedly embedded were a real existing mechanism that kept planets in their regular circular orbits, his empiricist rivals held that the spheres were merely mental connivances to give order to experience, they had no ontological reality. The debate was famously replayed when Cardinal Bellarmine urged Galileo to adopt an instrumentalist view of Copernican heliocentric astronomy – that heliocentrism was useful for astronomical calculations, but it was not actually how the solar system was arranged.

It is possible to make similar claims about each item on the Lederman list. Thus the field of NOS research in science education is yet another example where more cooperation between science educators, historians and philosophers would considerably improve the usefulness and quality of published work.

In addition to the foregoing five elaborated topics, an up-dated list of fields where HPS can fruitfully contribute to current science education research, curriculum development and pedagogy would include: *Ethics* (consider the research on 'teaching socio-ethical issues in science' as found for instance in *Science & Education* **17** nos.(8-9), *Rationality* (consider the widespread Kuhn-inspired dismissal of the rationality of science and of theory-change in science), and *Multiculturalism* (consider the widespread adoption of the 'multi-science' thesis among science educators, and the epistemological and cultural problems associated with the thesis (see Matthews 1994, chap.9)).

Conclusion

I have given here an account of what I see as the current engagement of HPS with science teaching and research; elaborations of this account can be found in Matthews (1994, 2000a, 2009a). New curricula are attempting to bring this engagement into the science classroom. The success of this will depend upon first introducing appropriate HPS courses into pre-service and in-service teacher education programmes. Science is one of the great achievements of human culture. If a richer HPS-informed understanding and appreciation of science, its methods and 'habits of mind', conjoined with familiarity with science-informed Enlightenment ideals, can be developed in science classrooms, then some beginning might be made in overcoming the well-documented crisis in contemporary science education, and also the daily newspaper and television documented myriad social and cultural crises the world faces.

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