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The Contribution of Philosophy to Science Teacher Education

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Abstract: Teacher education, more specifically science education, is not in good philosophical health. Competence in and appreciation of the history and philosophy of science (HPS) is required for teaching faculty and, to an appropriate degree, for graduating students. There are many reasons why HPS should be part of preservice and in-service science teacher education programs. Increasingly school science courses address historical, philosophical, ethical and cultural issues occasioned by science. Beyond these 'practical' arguments for HPS in teacher education, there are compelling 'professional' arguments. A teacher with pride in their profession must understand the body of knowledge they are teaching, how this knowledge has come about, how its claims are justified, what its limitations are and, importantly, what the strengths and contributions of science have been to the betterment of human life. Overall, the history and philosophy of science allows science teachers and science education researchers to better understand their own social and professional responsibilities as part of a great tradition, and so interest and competence in HPS needs be cultivated in teacher education and graduate courses.

There are many reasons why philosophy, and more specifically the history and philosophy of science should be part of science teacher education programs. Increasingly school science courses address historical, philosophical, ethical and cultural issues occasioned by science. Teachers of such curricula obviously need knowledge of HPS. Without such knowledge they either present truncated and partial versions of the curricula, or they repeat shallow academic hearsay about the topics mentioned. Either way their students are done a disservice. But even where curricula do not include such 'nature of science' sections, HPS can contribute to more interesting and critical teaching of standard curricula content.

Philosophical and Curricular Arguments for HPS in Science Education

Nearly fifty years ago Israel Scheffler argued for the inclusion of philosophy of science in the preparation of science teachers. It was part of his wider argument for the inclusion of courses in the philosophy of the discipline in programmes that are preparing people to teach that discipline. His suggestion was that: 'philosophies-of constitute a desirable additional input in teacher preparation beyond subject-matter competence, practice in teaching, and educational methodology' (Scheffler 1973, p.40). He summarised his argument as follows:

> I have outlined four main efforts through which philosophies-of might contribute to education: (1) the analytic description of forms of thought represented by teaching subjects; (2) the evaluation and criticism of such forms of thought; (3) the analysis of specific materials so as to systematize and exhibit them as exemplifications of forms of thought; and (4) the interpretation of particular exemplifications in terms accessible to the novice. (Scheffler 1973, p.40)

For the most part Scheffler's suggestion went unheeded: a fact witnessed to by the title of a 1985 paper 'Science Education and Philosophy of Science: Twenty-Five Years of Mutually Exclusive Development' (Duschl 1985).

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

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

These questions are of perennial concern to science teachers, and science teacher education programs. How can a science course, much less a science education, course progress without attending to these core questions? Nevertheless, Ennis was moved to make the melancholy observation that: 'With some exceptions philosophers of science have not shown much explicit interest in the problems of science education' (Ennis 1979, p.138).

Ennis did not use the expression 'nature of science' (NOS) but his list is essentially a philosopher's view of the contents of NOS. That topic is now found in the science curriculum of most countries in the world (Olson 2018). It is universally stated in those documents that science teachers, and students graduating from a school science programmes, need to have some appreciation of NOS. Some national and provincial curricula go further stating that such students should develop a scientific 'habit of mind'. Clearly these NOS aspirations require teachers to value and have a degree of competence in HPS.

Contemporary concern with teaching NOS is most clearly seen in affirmations of the American Association for the Advancement of Science, especially its landmark 1989 publication *Science for All Americans* (AAAS 1989) and its 1990 *The Liberal Art of Science* (AAAS 1990). The latter stated that:

> The teaching of science must explore the interplay between science and the intellectual and cultural traditions in which it is firmly embedded. Science has a history that can demonstrate the relationship between science and the wider world of ideas and can illuminate contemporary issues. (AAAS 1990, p.xiv)

This was elaborated in their *Benchmarks for Science Literacy* document (AAAS 1993). The AAAS believes that learning about science – its history and methodology - will have a positive impact on the thinking of individuals and will consequently enrich society and culture. That is, NOS learning will have a flow-on effect outside the science classroom. This was an essential belief of Enlightenment philosophers and educators (Matthews 2015a, chap.2).

The expectations of the AAAS found their way through to the *US National Science Education Standards* (NRC 1996). The *Standards* have a separate content strand devoted to 'History and Nature of Science Standards'.

The UK offers an example of taking these NOS aspirations very seriously. There a new optional Upper Level *Perspectives on Science* course was introduced in 2007 (Swinbank & Taylor 2007). The course has four parts:

Pt.1 Researching the history of science
Pt.2 Discussing ethical issues in science
Pt.3 Thinking philosophically about science
Pt.4 Carrying out a research project

The textbook for this course, on its opening page, says:

> *Perspectives on Science* is designed to help you address historical, ethical and philosophical questions relating to science. It won't provide easy answers, but it will help you to develop skills of research and argument, to analyse what other people say and write, to clarify your own thinking and to make a case for your own point of view. (Swinbank & Taylor 2007, p.vii)

The Philosophy section begins with about 16 pages outlining standard matters in philosophy of science – nature of science, induction, falsifiablity, paradigms, revolutions, truth, realism, relativism, etc. Importantly, the book then introduces the subject of 'Growing your own philosophy of science' by saying:

> Having learned something about some of the central ideas and questions within the philosophy of science, you are now in a position to evaluate the viewpoints of some scientists who were asked to describe how they viewed science. The aim here is to use these ideas as a springboard to develop and support your own thinking. (Swinbank & Taylor 2007, p.149)

Ennis's six questions are perennial, but NOS does not exhaust the field of HPS&ST concern. Historians and philosophers have usefully contributed to the improvement of classroom pedagogy, to curriculum development, and to better-grounded resolution of theoretical issues impinging on science education. The latter includes: feminist critiques of science, appraisal of multiculturalism and indigenous knowledge claims, evaluation of constructivist theory, environmental ethics, the teaching about worldviews in science classes, teaching evolution in cultures where it is rejected, common issues concerning science and religion, and so on. Teachers and administrators routinely face such theoretical issues, and they cannot be intelligently discussed without some explicit or implicit reference to HPS.

Liberal Science Education

The present rapprochement between HPS and science education represents in part a renaissance of the long-marginalised liberal, or contextual, tradition of science education, a tradition contributed to in the last hundred years by scientists and educators such as Ernst Mach, Pierre Duhem, Alfred North Whitehead, Frederick W. Westaway, E.J. Holmyard, Percy Nunn, James Conant, Joseph Schwab, Martin Wagenschein, Walter Jung and Gerald Holton. For liberal educationalists, education is more than the preparation for work;

education is valued because it contributes to the cognitive and moral development of both the individual and their culture (Bantock 1981, chap. 4, Peters 1966, chaps. 1, 2).

The liberal tradition maintains that science education should not just be an education or training *in* science, although of course it must be this, but also an education *about* science. Students educated in science should have an appreciation of scientific methods, their diversity and their limitations. They should have a feeling for methodological issues, such as how scientific theories are evaluated and how competing theories are appraised; how common controversy is in science and how scientific argument and debate is engaged in the resolution these controversies; and an appreciation of the interrelated role of experiment, mathematics, and religious, philosophical and ideological commitment in the development of science.

The liberal argument is that all students, whether science majors or others, should have some knowledge of the great episodes in the development of science and consequently of culture: the ancient demythologizing of the world picture; the Copernican relocation of the earth from the centre of the solar system; the development of experimental and mathematical science associated with Galileo and Newton; Newton's demonstration that the terrestrial laws of attraction operated in the celestial realms; Darwin's epochal theory of evolution and his claims for a naturalistic understanding of life; Pasteur's discovery of the microbial basis of infection; Einstein's theories of gravitation and relativity; the discovery of the DNA code, and research on the genetic basis of life. They should, depending upon their age, have an appreciation of the intellectual, technical, social and personal factors that contributed to these monumental achievements.

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

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

To teach Boyle's Law without reflection on what ‘law’ means in science, without considering what constitutes evidence for a law in science, and without attention of who Boyle was, when he lived, and what he did - is to teach in a disappointingly truncated way.

More can be made of the educational moment than merely teaching or assisting students to discover that for a given gas at a constant temperature, pressure multiplied by volume is a constant. This is something, but it is minimal. Similarly, to teach Darwinian evolutionary theory without considerations concerning theory and evidence, the roles of inductive, deductive and abductive reasoning, Darwin's life and times and the religious, literary and philosophical controversies his theory occasioned - is also limited. Students doing, and interpreting experiments need to know something of how description of data relies upon theory, how evidence relates to the inductive support or deductive falsification of hypotheses, how real cases relate to ideal cases in science, how messy 'lived experience' connects with abstracted and idealised scientific theories, and a host of other matters which all involve philosophical or methodological concerns.

Clearly all of these goals for general education, and for science education, require the integration of history and philosophy into the science curriculum of schools and teacher education programmes.

Research in History, Philosophy and Science Teaching

Connected with these curricular affirmations of HPS there has, pleasingly, been some rapprochement between the research fields and communities of history and philosophy of science and science education (Matthews 2015a, 2018). The journal *Science & Education* was founded in 1992 having a subtitle 'Contributions from History, Philosophy and Sociology of Science', with ten numbers being published per year (Matthews 2015b). The high volume and quality of research connecting history and philosophy of science (HPS) to theoretical, curricular, and pedagogical issues in science teaching (HPS&ST) research is evidenced in the 3-volume 76-chapter handbook on the subject which has some 10,000+ references (Matthews 2014).

Constructivism in Science Education

Among numerous pedagogical, curricular and theoretical issues to which HPS has contributed, just one – the appraisal of constructivism - will be further developed here in order to demonstrate the importance of HPS for the theory and practice of science education.

Constructivism as a theory of knowledge and learning has been the major influence in contemporary science and mathematics education; and in its post-modernist and deconstructionist form, it is a significant influence in literary, artistic, social studies, and religious education. Its impact is evident in theoretical debates, curriculum writing, and pedagogical practice in all of these subjects.

Peter Fensham claimed that 'The most conspicuous psychological influence on curriculum thinking in science since 1980 has been the constructivist view of learning' (Fensham 1992, p.801). A former president of the US National Association for Research in Science Teaching (NARST) said that: 'A unification of thinking, research, curriculum development, and teacher education appears to now be occurring under the theme of constructivism ... there is a lack of polarised debate' (Yeany 1991, p.1). Constructivism underwrites USA national teaching standards:

> Hence, the current teaching standards in the USA call for teachers to embrace a social constructivist view of learning and teaching in which science is described as a way of knowing about natural phenomena and science teaching as facilitation of student

> learning through science inquiry … In particular, the reform emphasizes teacher education by promoting social constructivist teaching approaches …. These sophisticated epistemological perspectives are promoted in the US science education reform documents as both learning goals and teaching approaches (Kang 2008, p.478, 480).

For many, constructivism was more than just a learning theory, or even an educational theory, but rather it constituted a worldview or *Weltanschuung*, as suggested in remarks such as:

> Constructivism offers a viable alternative view of knowledge, reality, science and education. … The constructivist view of education provides us with a hope for the future as individuals value their own and others' understandings, take responsibility for their own destinies, and lead us forward into a changing but promising world. (Davis, McCarty, Shaw, & Sidani-Tabbaa 1993, pp.628, 635)

And:

> To become a constructivist is to use constructivism as a referent for thoughts and actions. That is to say when thinking or acting, beliefs associated with constructivism assume a higher value than other beliefs. For a variety of reasons the process is not easy. (Tobin 1991, p.1)

The constructivist family is certainly a 'broad Church'. One early review of constructivist research identified the following varieties: contextual, dialectical, empirical, information-processing, methodological, moderate, Piagetian, post-epistemological, pragmatic, radical, realist, social and socio-historical (Good, Wandersee & St Julien 1993). To this list could be added humanistic constructivism (Cheung & Taylor 1991), didactic constructivism (Brink 1991), socio-transformative constructivism (Rodriguez 1998) and situative constructivism (Lave & Wenger 1991).

It is a difficult theory to pin down, as recognised by its one-time major champion in science education:

> As we have thought about constructivism, we have come to realize that it is not a unitary construct. Every day we learn something new about constructivism. Like the bird in flight it has an elusive elegance that remains just beyond our grasp. (Tobin & Tippins 1993, p.20)

Just how anything that remains permanently 'beyond our grasp' can be a theory of learning, or any guide for teachers, is not explained.

Constructivism is both a theory of learning (a psychological theory) and a theory of knowledge (a philosophical, and specifically epistemological, theory). A typical account of the theory is given by Catherine Fosnot in a much-cited constructivist anthology:

> Constructivism is a theory about knowledge and learning; it describes both what 'knowing' is and how one 'comes to know'. Based on work in psychology, philosophy, science and biology, the theory describes knowledge not as truths to be transmitted or discovered, but as emergent, developmental, non-objective, viable

> constructed explanations by humans engaged in meaning-making in cultural and social communities of discourse. (Fosnot 2005, p.ix)

This should not be a surprise as epistemology and psychology were conjoined in the writings of the founders of educational constructivism - Piaget, Vygotsky and Bruner. Piaget called this own theory 'Genetic Epistemology', and this philosophical concern is reflected in his book title - *Psychology and Epistemology* (Piaget 1972). Jerome Bruner speaking of his famous *Process of Education* book (Bruner 1960) that presented a constructivist alternative to didactic, transmissionist, behaviourist-informed 'banking' pedagogy wrote that:

> Its ideas sprang from epistemology and the sciences of knowing … all of us were, I think, responding to the same "epistemic" malaise, the doubts about the nature of knowing that had come first out of the revolution in physics and then been formalized and amplified by philosophy.' (Bruner 1983, p.186)

The major question for researchers, teachers and philosophers embracing this theory, was: What constitutes rational change? This, obviously, is not an empirical question, it is an epistemological question, and typically education researchers were not well prepared to answer it. Philosophy of education has been stripped out of teacher education programmes everywhere. And philosophy rarely features in education graduate programmes.

Thomas Kuhn's Imprint on Constructivism

Educational constructivism was born at the same time as the Kuhnian revolution in philosophy of science and was powerfully influenced by the latter. Joseph Novak, as with so many educators and scholars from all disciplines, was awed by Kuhn and the 'new wave' in historical-relativist philosophy of science that Kuhn's *Structure of Scientific Revolutions* (Kuhn 1970) launched:

> In philosophy, a consensus emerges that positivism is neither a valid nor a productive view of epistemology … What is emerging is a *constructivist* view of epistemology, building on ideas of Kuhn (1962), Toulmin (1972) and others. (Novak 1977, pp.5-6)

Jon Magoon, who arguably introduced the term 'constructivism' to education, shared Novak's enthusiasm for Kuhn:

> Kuhn's account of scientific progress and change from one approach to another has lessons for social and behavioral scientists as well as a likely parallel with regard to constructivism and traditional behaviorism and associationism today. (Magoon 1977, p.653)

Thomas Kuhn has arguably been the most influential historian of science in the twentieth century. His impact has been felt in all academic fields, and even beyond the academy. The first edition (1962) of his *Structure of Scientific Revolutions* sat largely unexamined on the publisher's display table, read only by a minority of historians and philosophers of science; the second edition (1970) exploded over the philosophical, and more generally scholarly landscape. It turned the heads of educators who rushed lemming-like over the Kuhnian cliff. They constituted a 'Kuhnian cheer squad' in the words of two researchers (Loving & Cobern 2000).

Largely on account of the unfortunate separation of Education Departments from Philosophy Departments, and the stripping of philosophy from teacher education and graduate education programmes, educators did not see the detailed criticisms of Kuhn that were advanced in the history and philosophy of science community. These began with Dudley Shapere who acknowledged the ‘vast amount of positive value in Kuhn’s book’ (Shapere 1964, p.393), but went on to argue that his truly revolutionary account of theory change in the history of science:

> … is made to appear convincing only by inflating the definition of "paradigm" until that term becomes so vague and ambiguous that it cannot easily be withheld, so general that it cannot easily be applied, so mysterious that it cannot help explain, and so misleading that it is a positive hindrance to the understanding of some central aspects of science; and then, finally, these excesses must be counterbalanced by qualifications that simply contradict them. (Shapere 1964, p.393)

Israel Scheffler advanced an 11-point critique of Kuhn’s arguments, one of which dealt with Kuhn’s charge of irrationality in paradigm choice:

> [it] fails utterly, for it rests on a confusion. It fails to make the critical distinction between those standards or criteria which are internal to a paradigm, and those by which the paradigm is itself judged. (Scheffler 1966, p. 84).

David Stove argued:

> Kuhn’s entire philosophy of science is actually an engine for the mass-destruction of all logical expressions … [he] is willing to dissolve even the strongest logical expressions into sociology about what scientists *regard as* decisive arguments. (Stove 1982, p.33)

Alexander Bird provided a sympathetic appraisal of Thomas Kuhn but correctly maintained that:

> Kuhn’s treatment of philosophical ideas is neither systematic nor rigorous. He rarely engaged in the stock-in-trade of modern philosophers, the careful and precise analysis of the details of other philosopher’s views, and when he did so the results were not encouraging (Bird 2000, p.ix).

The historian Jan Golinski, wrote:

> I see Kuhn as having little positive influence on philosophers and almost none (directly) on historians. His most significant influence within science studies was mediated by sociologists, whose reading of his work he specifically repudiated (Golinski 2012, p.15).

Abner Shimony, a physicist and philosopher, said of the key Kuhnian move of deriving methodological lessons from scientific practice that:

> His work deserves censure on this point whatever the answer might turn out to be, just because it treats central problems of methodology elliptically, ambiguously, and

without the attention to details that is essential for controlled analysis. (Shimony 1976, p.582).

Mario Bunge recounts in his autobiography that he attended an influential 1966 colloquium on causality convened in Geneva by Piaget in which Kuhn participated. Bunge observed:

> Kuhn's presentation impressed no one at the meeting, and it confirmed my impression that his history of science was second-hand, his philosophy confused and backward, and his sociology of science non-existent. (Bunge 2016, p.181).

Not only did educators miss the initial criticisms, they missed Kuhn's recanting of his positions. In his Robert and Maurine Rothschild lecture at Harvard University in 1991 he appraised the sociological turn in the history and philosophy of science, acknowledging that it was 'emphasized and developed by people who often called themselves Kuhnians' (Kuhn 1991/2000, p. 3), but added that 'I think their viewpoints damagingly mistaken, have been pained to be associated with it, and have for years attributed that association to misunderstanding' (Kuhn 1991/2000, p.3). In reviewing his achievements, he regretted writing the 'purple passages' in *Structures*. Unfortunately, it was often these passages that were taken up in the education community. By the time Kuhn regretted them and tried to close the stable door, they had bolted out into the text of thousands of higher degrees, articles and books.

The Kuhnian revolution had disastrous effects in education. Two generations of educators and their students were left wandering around in a Kuhnian fog of 'paradigm', 'incommensurability', 'conversion', 'different worlds', and so on. This confused discussion, hampered research, and dimmed whatever light might be shed on real educational and social problems (Matthews 2004).

Problems with Constructivist Epistemology

Constructivism emphasises that science is a creative human endeavour which is historically and culturally conditioned, and that its knowledge claims are not absolute. This is certainly worth saying, but it is a truism shared by all philosophers and historians of science. Beyond this widely-agreed truism, constructivism is committed to very disputed epistemological positions. At its core, social constructivism has a subjectivist and empiricist understanding of human knowledge, and consequently of scientific knowledge. As one of the most influential constructivists in science and mathematics education has put it:

> Knowledge is the result of an individual subject's constructive activity, not a commodity that somehow resides outside the knower and can be conveyed or instilled by diligent perception or linguistic communication. (Glasersfeld 1990a, p.37)

Constructivists are epistemological relativists. Consider, for example:

> The constructivist epistemology asserts that the only tools available to a knower are the senses. It is only through seeing, hearing, touching, smelling, and tasting that an individual interacts with the environment. With these messages from the senses the individual builds a picture of the world. Therefore, constructivism asserts that knowledge resides in individuals. (Lorsbach & Tobin 1992, p.5)

And:

> 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)

Such relativism has its philosophical problems, and these have been pointed out by many (Nola 1988, Norris 1997).

Problems with Constructivist Ontology

Constructivists often embrace an idealist ontology, or idealist theory about the existential status of scientific and everyday objects; that is, they variously maintain that the world is created by and dependent upon human thought. Various Kuhn-inspired sociologists of science repeatedly state that different observers 'live in different worlds' and that they create those worlds. These astounding claims pass over the major ambiguity: On the one hand the complete truism that different observers and different groups have different experiences; on the other, that the natural world in which they live varies from observer to observer and group to group. The latter is not a truism and requires some argument; as does the more advanced claim that these various worlds are created by the observer. Kenneth Gergen, an influential social constructivist, expresses this position, saying there is 'a multiplicity of ways in which "the world" is, and can be, constructed' (Gergen 1994, p.82). The social and cultural worlds do vary, that is an undisputed statement about social and cultural reality, but it has no bearing on the realist and universalist claim of a common natural world.

Ernst von Glasersfeld's radical constructivism is the best-known idealist variant in educational circles. He says:

> The realist believes his constructs to be a replica or reflection of independently existing structures, while the constructivist remains aware of the experiencer's role as originator of all structures . . . for the constructivist there are no structures other than those which the knower constitutes by his very own activity of coordination of experiential particles. (Glasersfeld 1987, p.104)

Realists need not make any such claims about 'replication' and 'reflection', they indeed make claims about the world, but recognise that 'there is more to seeing than meets the eyeball' and the claims are the outcome of social, personal and cultural circumstance. Elsewhere von Glasersfeld writes:

> I can no more walk through the desk in front of me than I can argue that black is white at one and the same time. What constrains me, however, is not quite the same thing in the two cases. That the desk constitutes an obstacle to my physical movement is due to the particular distinctions my sensor system enables me to make and to the particular way in which I have come to coordinate them. Indeed, if I now could walk through the desk, it would no longer fit the abstraction I have made in prior experience. (von Glasersfeld 1990b, p.24)

This argument has problems. For the realist, the inability of our body to 'walk through' another body has nothing to do with our sensory powers, but everything to do with the composition and structures of the bodies. Changing our sensory powers will no more allow us to walk through a hitherto impenetrable table, than changing our shirt would allow us to do so. Upon dying we lose all sensory powers, but this does not mean our body can then penetrate a table. Our having or not having sensory powers makes no difference to the penetrability of the table; to think that it does is just philosophical idealism.

Again, this is a flawed position. Observations and theory clearly depend upon us, but not the objects observed or their structures. Philosophical alarm bells should ring when an author runs together 'observations' with 'events' and 'objects'. For a realist, and for any serious scientist, there are categorical differences between these classes. Only a philosophical idealist can run them together without alarm bells ringing; and when they do ring the idealist case has to be argued, not just assumed.

Rosalind Driver, a rightly famous and influential science educator, frequently affirmed the idealist position. For instance:

> science as public knowledge is not so much a "discovery" as a carefully checked "construction" … and that scientists construct theoretical entities (magnetic fields, genes, electron orbitals …) which in turn take on a "reality" ' (Driver 1988, p.137).

Here it is being said that the earth does not have a structure until geophysicists impose it; there is not an evolutionary structure in the animal world till biologists impose such structure; atoms have no structure until such is imposed by physicists; and so on. One might ask: If gravity waves are our creation, why spend so much time and money looking for them?

Despite Driver's basic argument form being fallacious, it is nevertheless wide-spread. The argument has the form:

Premiss: Some concept is a human construction
Conclusion: Therefore the referent of the concept does not exist

One only has to state this argument to see that it is an invalid inference, and its validity depends upon making explicit a suppressed premiss of the form:

Suppressed premiss: All concepts that are human constructions can have no existential reference

But this suppressed premiss is simply dogma for which no evidence is provided. Not only are 'electron orbitals' and 'magnetic fields' human constructions, but so also are 'my house' , 'mountain', 'table' and all the other observational terms we use. If the foregoing widespread constructivist argument, utilised by Rosalind Driver, were valid, then not only would electron orbitals not exist, neither would our house, the tables in it, nor mountains that we might live near. Indeed, given that the personal pronoun 'I' is a human construction, individual cognizing subjects might not exist. But such considerations are frequently dismissed as 'philosophical quibbles'.

The Waning of Constructivism

Constructivism is fraught with grave educational and cultural implications that are seldom recognised much less engaged with. The 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 Enlightenment reason and the rejection of self-interest in the attempt to deal with pressing environmental, political and social questions. 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)

Two years of President Trump should be enough to send all constructivists running back to defend 'facts of the matter' and to regret their ever being so cavalier as to throw them out the cultural window. There are facts of the matter concerning climate change, the murder of Jamal Khashoggi, the impact of tariffs on US agriculture, the size of an inauguration crowd, and so on. For any school subject, much less science, to fundamentally assert that there are no facts of the matter, and more alarmingly, that there is no reality beyond what individuals construct for themselves, is to leave uncontrolled the dangerous narcissism of all tyrants and oppressors.

After sustained philosophical criticism, and more recently refutation of its claims to be a guide for successful pedagogy (Kirschner, Sweller, & Clark, 2006), there are signs that constructivist influence is waning. Thirty years ago there were hundreds of constructivist presentations at the US annual NARST and AERA conferences; in recent years only a handful of papers having 'constructivism' in their title could be found on the programme. The Constructivist SIG at AERA has basically closed shop, having just four papers in 2015. The most energetic figure in the field has 'Moved On' (Tobin 2000); while another enthusiast abandoned constructivism because 'it turned out to be plagued with considerable contradictions' (Roth 2006, p.326).

Most constructivists have moved on to Critical Studies or Cultural Studies (McCarthy 2018); but have taken constructivism with them. For Ken Tobin:

> In contrast to the mainstream of research in science education, I advocate a multilogical methodology that embraces incommensurability, polysemia, subjectivity, and polyphonia as a means of preserving the integrity and potential of knowledge systems to generate and maintain disparate perspectives, outcomes, and implications for practice. In such a multilogical model, power discourses such as Western medicine carry no greater weight than complementary knowledge systems that may have been marginalized in a social world in which monosemia is dominant. (Tobin 2015, p.3)

Who knows what this means? It is certainly 'beyond the grasp' of all but the most sophisticated initiates. It is a case study on the life-long effects of a poor grounding in philosophy. Constructivism may have been abandoned, but the intellectual habits have not been.

History and Philosophy of Science in Professorial and Teacher Formation

The paucity of serious HPS input into science teacher education is depressingly well documented in Peter Fensham's book *Defining an Identity: The Evolution of Science Education as a Field of Research* (Fensham 2004). The book opens a representative and authoritative window onto international science teacher education and the ethos of science education graduate schools. Fensham is one of the most respected and influential science educators of the past fifty years (Cross 2003). The *Identity* book is built around his interviews with 79 leading science educators from 16 countries; they include at least 16 past Presidents of the National Association for Research in Science Teaching (NARST), and 10-15 current or past editors of major international science education research journals.

The interviewees have authored or edited hundreds of books, a thousand or more research articles, and have overseen the same number, or more, of doctoral students. So although the book provides a numerically small sample of the profession, nevertheless it is a good sample of leading science education academics, and provides some reasonable warrant for extrapolation to the wider science education academic community. What it lacks in quantity it makes up for in quality.

The interviewees were asked by Fensham to respond to two questions (Fensham 2004, p.xiv):

 # 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.

The two philosophers most mentioned as influencing the intellectual formation of these leading researchers were the leading constructivists Thomas Kuhn and Ernst von Glasersfeld.

Kuhn is more cited than read; the mere citation of Kuhn is considered to constitute an argument or to provide evidence for some philosophical view. One interviewee in a publication writes that: 'In recent years, the rational foundations of Western science and the self-perpetuating belief in the scientific method have come into question …. The notion of finding a truth for reality is highly questionable' (Fleer 1999, p.119). No evidence is adduced for this sweeping claim except an unpaginated reference to Kuhn. This practice of having a Kuhn citation substitute for evidence or argument is widespread. Merely putting 'Kuhn' in brackets after some outrageous claim is regarded as sufficient warrant for the claim.

As documented in Fensham's book, as evidenced in any random sample of science education publications, and as indicated in the earlier sections of this chapter, the philosophical competence of science education faculty needs to be raised. The following are some steps that might be taken:

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, history or linguistics 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. Far better for science educators to spend a semester attending a philosophy, psychology, linguistics or history course, and reading substantial books, than running around conducting yet another study of misconceptions or the impact of talking on classroom learning. Better that a few things be done well than a hundred things be done poorly.

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.

Aside from preparing professors, the inclusion of some education-related HPS course in the preparation of science teachers is a necessity. Ideally it means the creation of specific courses that pick up tangible theoretical, curricular and pedagogical topics in science teaching that teachers can identify and recognise as genuine problems; then elaborate how HPS considerations can contribute to the better understanding and resolution of the issue. The following diagram - which is an elaboration of an informative comparable diagram in Roland Schulz (2014) – captures the components discussed above which support the formation of well-prepared science teachers.

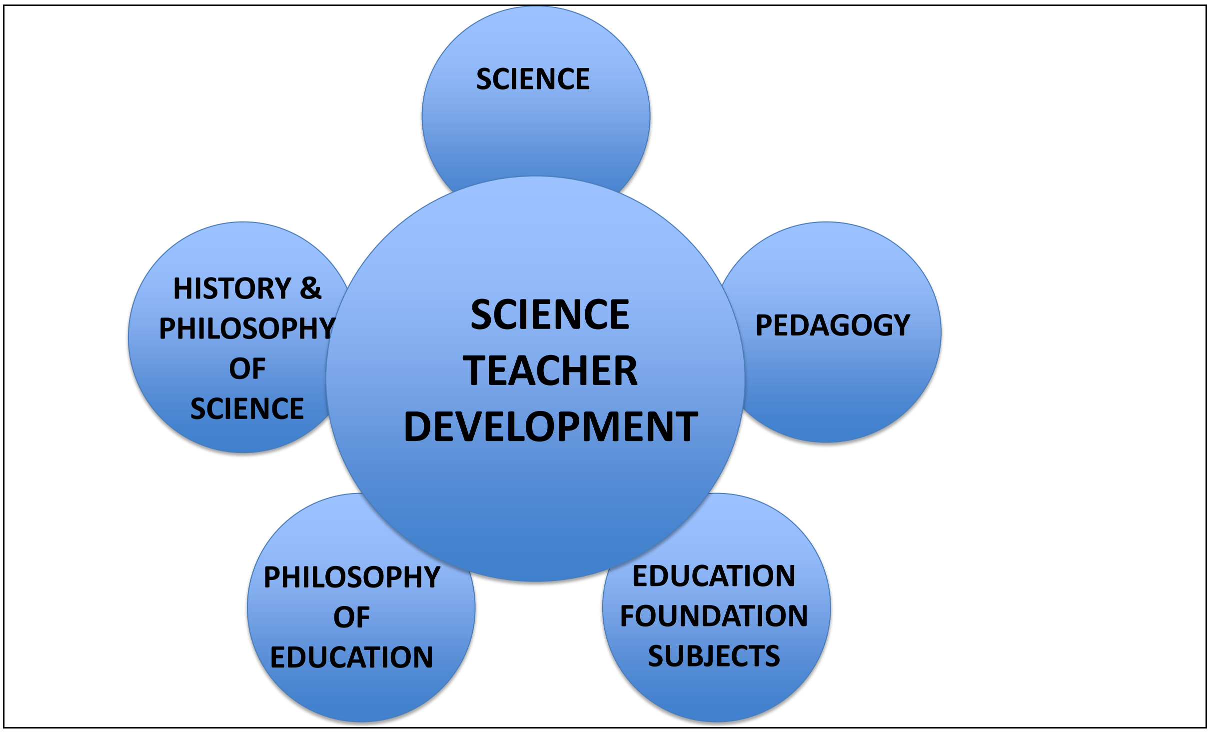

Fig.1, Science Teacher Development

SCIENCE: undergraduate and/or postgraduate science degree, etc.
HISTORY AND PHILOSOPHY OF SCIENCE: internal curriculum-based HPS and external education-related HPS studies, etc.
PEDAGOGY: practice teaching, educational technology, instructional theory, local curricular, assessment theory and practice, administrative matters, special-needs education, etc.

PHILOSOPHY OF EDUCATION: aims of education, personal and social goals of education, ethical standards for classroom teaching and teacher-student interactions, and for school systems, conceptual analysis of teaching and learning, etc.

EDUCATION FOUNDATION SUBJECTS: sociology of education, history of science education, psychology and cognitive science, developmental psychology, curriculum theory, etc.

Conclusion

Many of the issues in the history and philosophy of science are complex and contentious. The jury is still out on important matters, including constructivism discussed above. The art of the teacher is to judge the sophistication of his or her students and present a picture of science that is intelligible to them without being overwhelming. Students need to get their feet, to become familiar with a tradition, before they are confronted with the 'cutting edge' questions. The teacher may have strong opinions on various HPS issues, but the point of education is to develop the students' minds, which means giving students the knowledge and wherewithal to develop informed HPS opinions. If HPS in science teaching becomes a catechism, then it defeats one of its major purposes.

HPS in teacher training programs can do something towards broadening the vision of teachers, and having their students not only arrive at destinations (scientific competence), but arrive with broader horizons, having travelled with a different view. In the long run this contributes to the health of science.

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