## Commentary

# Philosophical Confusion in Chemical Education Research

by Eric R. Scerri

### The State of Research in Chemical Education

The positive strides that have been made in chemical education research are undeniable as are the contributions made by this *Journal* in furthering the development of the field. In this piece I would like to suggest that all may not be well, however, and that some simple measures could be taken to redirect the general outlook and thereby improve the reputation of chemical education research.

As a recent article pointed out, there are now a number of U.S. institutions that award a Ph.D. in chemical education research *(1)*. However, the field continues to be perceived by the vast majority of mainstream chemists with suspicion and sometimes even hostility. It is not uncommon to hear of junior tenure track faculty who are under undue pressure to perform according to unrealistic criteria set by departments that do not understand, or value, the nature of chemical education research. Indeed I have even heard from some full professors, in the few institutions that include specialists in chemical education, who complain of being marginalized and misunderstood by their colleagues in chemistry. One frequently hears it said that research in chemical education represents a soft-option best suited for those who are not capable of succeeding in "real chemistry" research.

Having said this, I believe that part of the blame for the current state of affairs lies not with the majority of mainstream chemists, but within the field of chemical education itself. One has only to attend a chemical education research session at a national ACS meeting to see that the field has become somewhat inward looking. One of the biggest problems, as I see it, is a failure to engage in issues of chemical content. Relatively little effort is put into trying to bridge the widening gap between front-line research in chemistry and the general chemistry curriculum, for example. Chemical education research frequently withdraws into producing better visualization and developing multimedia projects in the hope of improving the teaching of chemistry. For all their ingenuity such innovations often leave the subject of chemical content as a mysterious black-box that is supposed to look after itself. Mainstream chemists understandably view such activities as superficial busywork.

But in this article my aim is to concentrate on another aspect of research into chemical education that I and others believe to be harmful to the reputation of the field. I am referring to what can only be described as dubious and abstract theoretical issues revolving around the themes of constructivism, relativism and other philosophical *-isms*.

I am referring in particular to the work of some chemical educators who call themselves constructivists. Of course the mere adherence to a constructivist perspective need not be taken to signal any form of radical constructivism, of a social or individual kind, which has recently incensed the scientific community *(2)*. Nevertheless I think that if one looks closely at the basic philosophical positions offered by some contemporary chemical constructivists one sees many radical themes that are not only open to serious questioning but can also be construed as being anti-scientific. In other cases I will argue that chemical educators who describe themselves as constructivists are unwittingly arguing for a very traditional conception of scientific knowledge that sits rather uncomfortably with constructivism as generally understood in the context of scientific theories. According to a recent introduction to the philosophy of science, for example, constructivism is the view that *(3)*,

> …the entities in some domain exist, but are mind-dependent in the sense of not existing over and above our construction of them.

In all the cases to be examined I will be more concerned with philosophical motivations and commitments, as far as these may be discerned, than with detailed chemical examples, although some of the latter will also be touched on briefly.

### The Origins of Chemical Constructivism

In a much-cited article that is now regarded as the manifesto for chemical constructivism, Dudley Herron drew on Piaget's stages of psychological development and especially the transition between concrete and formal thinking *(4)*. Herron argued that many high school and even beginning college students may not have effected the transition to Piaget's stage of formal reasoning and that we should take account of this fact in the way in which chemical education is approached. For example, in discussing the topic of acid–base chemistry, Herron adopts what is clearly an empiricist stance when he writes,

> I have suggested that the concept of an acid as anything that will turn litmus red is a concrete concept. The meaning of the concept is easily apprehended from sensory observation and requires simple classification skills. But I have also suggested that the concept of an acid as anything that will produce hydrogen ions in water solution (Arrhenius), as a proton donor (Brønsted-Lowry) or as an electron-pair acceptor (Lewis) is formal. The meanings of acid cannot be made clear through the senses directly since there is no way to sense protons or electron pairs. Rather this concept of acid can have meaning only through imagination or through logical thought about the nature of molecules which interact.

Piaget's sense of concrete is being interpreted here in a narrowly empiricist fashion. It would seem that only things that can be seen, or sensed directly, are regarded by Herron as being concrete. The author then proceeds to suggest a simple means whereby the formal may be rendered more concrete.

> In the case of the concept of an acid, for example, I believe we can do very well if we made extensive use of physical models in which we show to students a ball representing a proton being removed from an acid substrate. The model is concrete and the student can imagine the process which we describe in terms of this model.

I believe that Herron has introduced something of an inconsistency, since the kind of empiricism he appeals to, namely the demand that scientific knowledge should have its foundation in sense perception, stands in direct opposition to virtually all forms of constructivism. Constructivism instead upholds that scientific knowledge is not so much discovered but negotiated or "constructed" by social factors or in the mind of the scientist or the learner.

## A Redox Example

Indeed I believe that Herron's philosophical position is rendered more confusing when he then turns to discussing the means through which the topic of redox could be better presented in chemical education.

> I would argue that the presentation of oxidation and reduction as the loss and gain of electrons requires formal thought whereas the presentation of oxidation and reduction in terms of a gain and loss in oxidation number requires only concrete thought.

I think that many chemical educators will join me in regarding oxidation number as a concrete concept may be somewhat counter-intuitive. After all, the concept of oxidation number is regularly described as an artificial but useful concept in nearly all textbooks of chemistry. Alternatively one could heed the advice given above by Herron concerning the building of realistic models to illustrate the nature of acids. One could do the same for the redox behavior of an atom or molecule, by building a model, to show the removal or addition of electrons in order to reinforce the more concrete aspects of, say, the Lewis definition of acids and bases.

In any case it is not essential to apprehend atoms directly with the senses in order to regard them concretely. Contemporary students, and educators alike, now regard atoms and molecules just as concretely as pieces of litmus paper. This is especially true given the advent of scanning tunneling microscopy and the images of atoms that are regularly seen in chemistry textbooks.

Whatever the specific answers might be to these questions, I believe that there is much work to be done in trying to develop a consistent philosophical position and in trying to clarify just what kind of constructivism Herron might be presenting. As things stand, he seems to be unwittingly arguing for a very traditional conception of scientific knowledge that sits rather uncomfortably with constructivism in the sense that it is used in philosophy of science. For example, another recently given definition of this term is that, *(5)*

> Constructivism is the suggestion that the laws of nature as we know them are social constructs—essentially laws that scientists have agreed between themselves and do not have any fundamental significance.

Or as other authors have expressed it, constructivists believe that it is not Nature but the scientific community itself that selects among possible laws of nature.

Nevertheless, I would like to make it clear that Herron's views seem to be less off the mark philosophically than those on which I will comment below. Similarly, I emphasize that I am criticizing Herron for a possible lack of clarity and not suggesting that he is in any sense anti-scientific.

## Behaviorism

Constructivism is not the only term that seems to have a different meaning in pedagogy from the meaning it has in other fields, such as philosophy and psychology. Unfortunately this distinction is not made by chemical constructivists. For example, another chemical educator who considers himself as a constructivist has stated his view of the term "behaviorism" rather explicitly *(6)*.

> The traditional method of teaching science has its roots in what is called "behaviorism", which is the belief that an idea can be transferred intact from the mind of the instructor to the mind of the student, or that telling is teaching. An alternate methodology, the cognitive learning paradigm, stresses the thought process of the learner and assumes that prior knowledge, attitude, motivation and learning style affect the learning process. Recently there has been a slow shift from the behavioral to the cognitive paradigm or, in the current terminology, from objectivism to constructivism.

But if one were to consult any standard dictionary for the meaning of behaviorism, one would find it defined as something along the following lines *(7)*,

> The theory or doctrine that regards objective and accessible facts of behavior or activity of man and animals as the only proper subject for psychological study.

I suggest that it is difficult to see much connection between the sense of this term as used by contemporary chemical educators and this kind of more generally accepted definition of behaviorism.

The same author then proceeds to give what can only be described as an over-simplistic, point-by-point, comparison between what he terms "objectivism" and "constructivism" (see Table 1).

Unfortunately this tendency of presenting constructivism as though it were a form of weight reduction program, complete with "before and after" snapshots, is only too common among some chemical educators.

Without any qualification, the statement that "truths are independent of the context in which they are observed" is in fact correct, contrary to what the author implies. In addition it is an essential belief for anyone either practicing or teaching science. If one were to believe the entry in Table 1, one might conclude that a scientific truth would differ according to whether it was obtained at different geographical locations or at different times of day, which is patently nonsensical.

Similarly, without the slightest qualification, the statement that "knowledge is constructed" is either simply incor-

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**Table 1. Comparison of Objectivism and Constructivism**

| Objectivism | Constructivism |
|---|---|
| Truths are independent of the context in which they are observed. | Knowledge is constructed. |
| Learner observes the order inherent in the world. Aim is to transmit knowledge experts have acquired. | Group work promotes the negotiation of and develops a mutually shared meaning of knowledge. Individual learner is important. |
| Exam questions have one correct answer. | The ability to answer with only one answer does not demonstrate student understanding. |

rect or else so uncontroversial as to be completely redundant. If the author implies that human foibles determine whether the magnitude of the speed of light in a vacuum is either 3 or 4 or $5 \times 10^8$ m/sec approximately, this is patently untrue. If, on the other hand, the author is referring to the fact that all scientific knowledge is devised by human beings rather than being given to us directly by God or Nature, then of course everyone, even the most rabid "objectivist", would surely concur with this view.

Without getting too sidetracked on the issue of truth, perhaps a small digression is in order. It could be objected that the history of science is littered with many refuted theories and that consequently it is a mistake to believe that science ever provides the truth. One might be tempted to believe that there is some parallel between scientists constructing their knowledge of the world and students constructing their views of mature science. But I believe that it would be a mistake to draw such a parallel.

Since Karl Popper published his influential views, it has generally been accepted that all scientific knowledge is tentative, although it might still be approaching some intangible "truth". Such a concession need not imply the view that mature scientific knowledge is constructed in the sense that many sociologists of science imply.

The third entry in the table might also strike many readers as a gross over-simplification. Unless the author is prepared to qualify the bland statement that "exam questions have one answer", which he implies to be mistaken, I don't believe he is expressing any position whatsoever. If the exam question is something along the lines of "what is the velocity of light?" then even a radical constructivist would have to concede that there is indeed only one correct answer, unless one is referring to the possibility of quoting the velocity to varying degrees of accuracy. I am of course choosing my example rather deliberately since the velocity of light in any particular medium is completely invariant. In this instance there is absolutely no possibility of there being more than one response to the question of its velocity.

Alternatively, if the author is thinking of an open-ended question such as whether Bohr's theory fully resolved the question of the collapse of the Rutherford atom, then most people would agree that there may be more than one answer. As in the previously considered example, one does not need to be a constructivist in order to accept the entries in the right hand column of the table under certain circumstances. But to claim that knowledge is constructed in general or that the majority of exam questions have more than one answer is, I believe, the height of folly.

I suggest that it is not mature scientific knowledge that is constructed, but only the student's understanding of mature science, a theme that I return to below.

## Relativism

One of the worst confusions that has been unleashed onto chemical educators in the name of constructivism has been the notion of relativism as it has been embraced in some quarters. In an unpublished but widely distributed article, as well as one published in this *Journal,* some other leading chemical constructivists leave the reader in no doubt about their own stance on relativism *(8)*. As in the case of the author cited in connection with "behaviorism", these other chemical constructivists appear to have latched onto a rather idiosyncratic interpretation of a philosophical position that they claim to support. This is what they say about relativism.

> The difference between the traditional and constructivist theories of knowledge mirrors the difference between the philosophy of science known as realist, objectivist, or positivist and the philosophy of science known as relativist… Realists believe that logical analysis applied to objective observations can be used to discover the truth about the world in which we live. They view knowledge in science as cumulative; it builds upon existing knowledge as science progresses. They believe we can separate objective truth from our "means of knowing it". In other words the identity of the researcher and the choice of research methodologies will have no effect on the truth that comes out of the research… Relativists accept the existence of the world but question whether the world is "knowable". They note that observations, and the choice of observations to be made, are influenced by beliefs, theories, hypotheses, and background of the individual who makes them. Statements about these observations are then expressed in a language whose words are embedded in a particular theoretical framework. Relativists therefore question whether a truly unbiased, objective observer can exist.

I think this is a gross misrepresentation of realism as well as relativism. First of all, to lump together realism, objectivism and positivism is rather misleading, as is the implication that these positions are necessarily outdated and inappropriate. Objectivism and realism, among the three positions grouped together, remain perfectly viable and are supported by the vast majority of contemporary scientists and philosophers of science. One does not need to be a relativist to accept that observations are influenced by the beliefs, background theories and hypotheses of the observer. Most

objectivists or realists would happily concede these rather uncontroversial claims regarding scientific knowledge.

Contrary to what these authors are claiming, the central idea in relativism is precisely that all knowledge is relative. This implies that the forms of knowledge derived from chemistry, black magic, or voodoo, for example, are all equally valid. Surely anyone who believes that science is worth teaching, in preference to these other pursuits, would not claim allegiance to this more correct understanding of the term relativism. The only person to my knowledge to ever propose such an outrageous view, and in very similar terms, was the self-proclaimed anarchist of science, Paul Feyerabend *(9)*. But even Feyerabend conceded that unlike political anarchists, he did not intend others to take him seriously!

Another sense of relativism concerns science itself and may have been inadvertently encouraged by the writings of Thomas Kuhn. It is that no two theories can be truly compared since they are expressed in different "languages" in which even the same terms may have different meanings *(10)*. But Kuhn himself did not share such relativistic implications of his work on incommensurability and on more than one occasion declared that he was "not a Kuhnian".

For a philosopher to be accused of being a relativist is tantamount to an accusation of sinning against rationality itself for a very simple reason. If all forms of knowledge are relative, why should one accept relativism itself as a worthwhile view to adopt? Relativism is therefore a self-defeating position. I cannot believe that any scientist would seriously contemplate relativism as a viable philosophical position regarding the nature of scientific knowledge, nor can I believe that science educators would be prepared to accept such a view. And yet this is precisely what the above-cited authors are recommending, in the belief that it represents a more enlightened and more modern philosophical position.

In any case, even the more extreme philosophers and sociologists of science who claim to be relativists have been forced to moderate their position in the light of criticism. It appears to have escaped the attention of the chemical constructivists that leading relativists like Collins have for some time been advocating what they term methodological relativism as opposed to full-blown, or philosophical, relativism *(11)*. What Collins now holds is that,

> Methodological relativism says nothing direct about reality or the justification of knowledge. Methodological relativism is an attitude of mind recommended to the social-scientist investigator: the sociologist or historian should act as though the beliefs about reality of any competing groups being investigated are not caused by reality itself.

Whether this does actually represent a distinct position to full-blown relativism is a topic of some discussion in the literature. But the fact remains that even the most extreme relativists such as Collins are trying to distance themselves from full-blown relativism. Meanwhile the chemical educators quoted above still cling to the extreme version of relativism in the mistaken belief that it represents an improvement on "objectivism, positivism and realism".

## The Difference Between Objectivism, Realism, and Positivism

I would like to take a moment to distinguish between three positions which the cited chemical educators have conflated, and to examine their implication that these positions have now been superceded.

Let us consider objectivism first. This term is often seen as providing the most appropriate polar opposite to relativism. Objectivism is taken to mean the basic conviction that there must be some permanent, ahistorical framework to which we can ultimately appeal in determining the nature of knowledge, truth and reality *(12)*. Objectivism is closely related to foundationalism and the search for an Archimedean point. Relativists deny these objectivist claims and go further in claiming that whatever others have taken to be fundamental concerning rationality, truth and knowledge must be regarded as relative to a conceptual scheme or paradigm. For relativists there is no overarching framework by which we can judge the claims of alternative paradigms.

Meanwhile positivism and realism represent more restricted positions than objectivism, which also differ from each other in some rather fundamental ways. The demand for observational evidence in the form of sense experience is the main characteristic of positivism. Ernst Mach, the arch positivist, did not believe in the reality of atoms because he claimed there was no direct observational evidence for these entities. On the other hand, one of the main beliefs of scientific realists is that non-observable scientific terms such as quarks really exist. On this point realists are diametrically opposed to positivists, hence a simple conflation of the two positions is seriously mistaken.

## Not Wishing To Throw Out the Baby with the Bath Water

To do full justice to the question of constructivism in science education would necessitate a discussion of how this term is used by philosophers, sociologists and anthropologists on one hand and science educators on the other hand. It is important to distinguish the radical claims of the first category of authors who maintain that scientific knowledge itself is obtained by a process of negotiation and social forces from the claims of constructivists in science education.

The first group of authors opposes the traditional belief that scientific knowledge results from investigating the way the world actually is. The claims made by most constructivists in the educational sphere are more modest. They are that students develop their understanding of science in a constructivist manner because of any preconceptions and misconceptions which they might bring to chemistry classes. One can hold such views about learning science while at the same time rejecting the more radical philosophical constructivism that holds that scientific knowledge itself is arrived at by a process of social negotiation.

Fully mature scientific knowledge, of the form that commands widespread consent by the community of scientists, does not differ according to the pedagogical evolution of the particular scientist concerned. Of course the views of mature scientists may well have begun as "constructions" that

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were indeed influenced by all manner of social or psychological factors, but mature science is largely free of personal idiosyncracies.

If on the other hand some chemical educators do wish to support the more radical claim that mature science itself shares constructivist elements, they should make this more explicit in their writings. One suspects that only a small minority of chemical educators, all of whom were trained as scientists, would want to go quite so far. As I see it, the majority of educators are understandably attracted to educational constructivism, but overstate their case by drawing support from the more extreme and often anti-scientific writings of constructivists.

Of course each individual developing student may have a different initial conception of any particular phenomenon and granted this conception may be relative to the educational and sociological background of the individual. But the process of learning science, unlike any other field, involves reaching a position where the student has understood enough of the shared, and temporarily accepted, store of knowledge so that he or she can communicate with others and even make contributions to the general scientific consensus.

I applaud chemical constructivists for encouraging teachers to be more conscious of the fact that students come to the study of chemical topics from a great variety of backgrounds. But in their appeal to concepts like constructivism and relativism, which are essentially being borrowed from philosophy and sociology, they need to make it quite clear that it is not the same brand of constructivism or relativism that they are supporting in the context of pedagogy. I believe that the present appeal to a nonspecific "constructivism" is ambivalent and continues to cause confusion.

The only such qualification by a constructivist, that I am aware of, has been made by Herron in his book on chemical education *(13)* in which he cites another author approvingly as saying,

> Even though in some "ultimate" sense there is no way to determine whether one paradigm is a better approximation to the "real" laws on nature than another, the exclusion of nature and the empirical world from our model of how scientific knowledge grows makes it difficult to understand why some knowledge enters the core and most does not. Thus it is on practical sociological grounds that I select my realist perspective.
>
> Nature poses some limits on what the content of a solution adopted by the scientific community can be. By leaving nature out, the social constructivists make it difficult to understand the way in which the external world and social processes interact in the development of scientific knowledge *(14)*.

Herron then adds,

> If we are to understand learning, the only viable position to take is that an external reality exists, even though the understanding of it may differ from one person to another and from one point in time to the next.

Although this word of caution represents a welcome improvement on the writings of other chemical construc-tivists, it does not go nearly far enough in moderating the radical constructivist claims. It addition it fails to distinguish clearly between the notion that mature science might be constructed and the distinct notion that students' understanding of science might be constructed. The author unfortunately also adds a footnote to tell readers that they can safely skip this entire section since it deals with an "obtuse point". As I see it, this section is absolutely essential to anyone involved in chemical education who might be drawn to constructivism and should be made required, rather than optional, reading.

It is also rather unfortunate that Herron's followers in chemical education research, some of whom have been cited in the present article, have not seen the need to specify the precise sense in which they are using such terms as relativism. As I suggested earlier, some chemical educators appear to support an unqualified form of relativism that I maintain is quite anti-scientific in spirit.

### Does Any of This Matter?

Some readers may be asking whether any of these philosophical concerns have any real importance in chemical education. I have written this commentary because I believe that these issues are indeed important and that chemical education is currently too simplistic in its underlying ideas.

None of this is very conducive to the growth and wider acceptance of chemical education research. I believe it is time for chemical educators to become more philosophically discerning and to begin to address the kinds of issues I have raised here. Otherwise they will be adding further fuel to what scientists generally regard as the "wrong side" of the science wars debate.

### Science Wars

Science Wars is the name that has been given to the vociferous debate that has been recently raging within the intellectual community, and even beyond it. Although many earlier skirmishes may have led up to the recent conflict, most commentators seem to agree that the outbreak of Science Wars was signaled by the appearance of a book by Gross and Levitt entitled *Higher Superstition (15).* The charge made by these authors was that many modern scholars who have written on the nature of science have seriously erred and are having a damaging influence upon scholarly work, the public image of science and, last but not least, on science education.

Briefly put, the complaint by those defending the traditional understanding of science is that some sociologists, anthropologists, literary critics and others have espoused relativistic views that threaten to undermine the very fabric of scientific knowledge. The opposing side, many of who belong to the intellectual movement known as Science Studies, have defended themselves in tones that are no less strident than those of their detractors. Many of the members of this opposing faction hold constructivist views about scientific knowledge and about the learning of science. They draw their inspiration from a variety of sources ranging from Thomas Kuhn, in history and philosophy of science, to Jean Piaget, in psychology.

More recently Science Wars reached something of a crescendo following the publication of Alan Sokal's hoax article in the journal *Social Text (16).* Sokal is a theoretical physicist, who believes that the post-modern commentators on science are mistaken. He wrote a paper in which he imitated the style of these commentators by drawing a number of nonsensical analogies between work in the humanities and modern physics and mathematics. As is well known, Sokal's article was accepted by the journal in question and published. At the same time the author revealed, in another journal, that it had all been a prank intended to expose the sloppiness of the review process and the fact that complete nonsense can apparently be made to pass for scholarly work in some circles *(17).* The outcome of Sokal's ingenious mischief has been to further polarize the already divided academic community and also to bring the issue to the attention of lay readers. The fallout of the Sokal affair has been aired in many commentaries, editorials, and debates that have appeared in newspapers and public forums of various kinds.

## The Role of Chemistry?

It would appear that in keeping with the surprisingly low profile that they display in matters relating to philosophy of science, chemists have likewise been almost completely invisible in the course of Science Wars, with just a few exceptions *(18–21).* But I would like to suggest that the chemical educators that I cited earlier, in particular, are also actors in the unfolding drama. In addition I claim the more startling notion that, unbeknown to themselves, these chemical educators appear to be fighting on the wrong side of the battle in that they are aligning themselves with the critics of science. I think that if one looks closely at the basic philosophical positions offered by these and other contemporary chemical constructivists, one sees many radical themes that leave one in no doubt that many of them have indeed defected to what most scientists would regard as the other side.

## Is There a Remedy?

In case I come across as advocating less philosophy in chemistry and chemical education, let me make myself clear. What I am recommending is a more careful use of philosophy in educational issues.

The simple remedy is for chemical education researchers to become better acquainted with the philosophical positions that they appeal to in their writings. Secondly, it has become increasingly clear to philosophers of science that it may be impossible to formalize or even characterize science as a whole in a successful manner. The three main natural sciences of physics, chemistry, and biology show considerable differences among themselves, and what is true of physics is probably not true of biology, to consider the most obvious contrast. This is why philosophers of science have largely forsaken the search for an all-encompassing account of the scientific method and have concentrated instead on developing philosophical understandings of each separate natural science. Meanwhile, others have chosen to focus on particular topics such as explanation, laws, or causality in science. Gone are the days of "heroic philosophy of science" when a Popper, Kuhn, or Lakatos would dare to pronounce on the whole of science. It is partly because these philosophers attempted to cast their nets too widely that they may have failed to obtain any lasting criteria to describe the nature of the scientific method.

And yet chemical constructivists continue to base a large part of their work on the views of Kuhn or Feyerabend, to cite the most popular choices. Chemistry, just like any science, has its own philosophical peculiarities that have been the focus of much investigation since the rebirth of philosophy of chemistry in the early 1990s. Although philosophy of chemistry is now the fastest growing sub-field in philosophy of science, it has been almost completely ignored by chemical education researchers, with the sole exception of Erduran *(22).* Many resources are now available in philosophy of chemistry—all that is required is for chemical educators to begin to draw upon them *(23–29).*

Chemistry is partly a liberal art, and is as much about thinking as it is about synthesis, experimentation, and computation. It is unfortunate that philosophy, which provides the most systematic analysis of ways of thinking, has been traditionally neglected by chemists. Even if chemical educators are not drawn to such positive recommendations as to why they should take an interest in philosophy, they should at least strive to obtain a good understanding of those philosophical concepts that have already crept into chemical education for better or for worse. Now that the situation has begun to change and philosophy of chemistry has become an established discipline, there is absolutely no excuse for sloppy philosophical thinking.

Just as scientists tend to be suspicious of the anti-scientific lobby in the Science Wars debate, they are also correctly suspicious of educators who openly espouse relativistic views about science. The recognition that individual students bring a variety of preconceptions to the study of chemistry is a very valuable one, but this should not commit educators to relativistic views about the nature of mature science.

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*Eric R. Scerri is in the Department of Chemistry & Biochemistry, University of California, Los Angeles, Los Angeles, CA 90095;* scerri@chem.ucla.edu.