Constructivism, Relativism, and Chemical Education

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ABSTRACT: Whereas most scientists are highly critical of constructivism and relativism in the context of scientific knowledge acquisition, the dominant school of chemical education researchers appears to support a variety of such positions. By reference to the views of Herron, Spencer, and Bodner, I claim that these authors are philosophically confused, and that they are presenting a damaging and anti-scientific message to other unsuspecting educators. Part of the problem, as I argue, is a failure to distinguish between pedagogical constructivism regarding students' understanding of science, and constructivism about the way that scientific knowledge is acquired by expert scientists.

KEYWORDS: constructivism; relativism; chemical education; Science Wars; realism

INTRODUCTION

For some years, the academic world has been in the midst of a fierce debate that shows little sign of abating. I am referring to what is popularly knows as the Science Wars, which began following the publication of Gross and Levitt's book entitled "Higher Superstition."[1] The charge made by these authors was that many who have written on the nature of science are seriously mistaken and are having a damaging influence upon scholarly work, the public image of science, and last but not least, on science education.

Briefly put, defenders of the traditional understanding of science (such as Gross and Levitt) complain that some sociologists, anthropologists, literary critics, and others have supported relativistic views, which threaten to undermine the fabric of scientific knowledge. The opposing side, which includes many of those belonging to the discipline that calls itself Science Studies, has defended itself in equally strident terms, although not as convincingly, to my mind. Many of the members of this opposing faction support 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. There is much variety regarding the meaning of terms such as "constructivism"

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among authors, and this has added to the general confusion among Science Wars adversaries and even allies.

More recently, the Science Wars reached something of a crescendo following the publication of Alan Sokal's article in the journal *Social Text*.[2] Sokal, a theoretical physicist who believes that the postmodern commentators on science are mistaken, wrote a paper in which he imitated the style of these scholars by drawing analogies between research in modern physics and mathematics. Sokal's article was accepted by the journal in question and promptly published. At the same time, the author revealed, in another journal, that the article had been a prank intended to expose the sloppiness of the review process among postmodern commentators on science. His prank seemed to show that complete nonsense could apparently be made to pass for scholarly work in these circles.[3] Not only did Sokal's ingenious mischief inflame passions within the already divided academic community, it also attracted the attention of lay readers. The fallout of the Sokal affair has been examined in many commentaries, editorials, and debates appearing in newspapers and public forums of various kinds.

WHAT ROLE FOR CHEMISTRY IN THE SCIENCE WARS?

It appears that, in keeping with the low profile they display in philosophy of science, chemists have been almost completely invisible in discussions on the Science Wars, with just a few exceptions.[4] But I would like to suggest that some chemical educators (I will cite a few below) are also actors in the unfolding drama, in a way that has not been generally acknowledged. In addition, I advance the more startling notion that, unwittingly, these chemical educators are fighting on the wrong side of the battle. If one looks closely at the philosophical positions offered by these chemical educators, one sees many radical themes that confirm that many of them have indeed defected to what the science lobby would regard as "the opposition."

As a recent article pointed out, there are now a number of U.S. institutions that award Ph.D.'s in chemical education research.[5] However, the field continues to be viewed by the majority of mainstream chemists with suspicion, and sometimes even with 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 research in chemical education. Indeed, one hears from some full professors, in the institutions that do have specialists in chemical education, that these are marginalized and misunderstood by their traditional chemical colleagues. It is frequently said that research in chemical education represents a soft option, suited for those who are not capable of succeeding in "real chemistry."

I believe that part of the blame for the current state of affairs lies, not with the majority of mainstream chemists, but with the field of chemical education itself. One has only to attend a chemical education session at an American Chemical Society meeting to see that the field has become somewhat inward looking and self-congratulatory. One of the biggest failings, as I see it, is a lack of engagement in issues of chemical content. Instead, chemical education research frequently withdraws into producing better visualizations, and developing multi-media projects, in the hope of improving the teaching of chemistry. 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.

In this article, my aim is to concentrate on another aspect of research in chemical education, one that I believe to be more harmful to the reputation of the field. I refer especially to some dubious and abstract theoretical issues revolving around the themes of constructivism, relativism, and other philosophical "-isms."

My focus in what follows will be on the work of some chemical educators who call themselves "constructivists." Of course, mere adherence to a constructivist perspective need not be taken to mean any form of radical constructivism, of a social or individual kind, such as that which has recently angered the scientific community. But if one looks closely at the philosophical positions offered by some contemporary chemical constructivists, one sees many radical themes that are not only open to serious question but can also be construed as being anti-scientific. In other cases, I will suggest that chemical educators who call themselves constructivists are unwittingly supporting a very traditional conception of scientific knowledge that sits rather uncomfortably with constructivism as generally understood. In the following cases, 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.

ORIGINS OF CHEMICAL CONSTRUCTIVISM

In a much-cited article that is regarded as a manifesto for chemical constructivism, Dudley Herron drew on Piaget's stages of psychological development and especially the transition between concrete and formal thinking.[6] Herron has become the undisputed leader in the movement to further what I will term "chemical constructivism." He is widely quoted in this context by authors who then proceed to offer what they regard as experimental support for the use of constructivism in chemical education. From a philosophical perspective, this tendency seems rather inexplicable. I can only surmise that the term constructivism is being used in a quite different sense of psychological or pedagogical constructivism rather than the philosophical or social constructivism often associated with Thomas Kuhn and others. But presumably there should be a connection between these two different forms of constructivism since a society of scientists comprises a collection of psychological individuals. If constructivism operates at the social level it might presumably be due to its also operating at the individual level. Perhaps some of the confusion philosophers experience on hearing the views that are voiced in chemical constructivism, and science education generally, is due to the gap between these two levels, the psychological and the social.

But to return to Herron, I believe that he is at heart an empiricist and that he makes no secret of this fact in many of his writings. Why he or his followers should label such views with constructivism is something that I propose to explore a little in this article. Herron has argued, as did Piaget before him, that many high school and beginning college students may not have effected the transition to the stage of formal reasoning. Herron's response is 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 seems to be an essentially empiricist stance.

> 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 (Brnnsted-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.[7]

It appears that Herron is interpreting Piaget's sense of the concrete in a narrowly empiricist fashion. Clearly Herron regards only things that can be seen, or sensed directly, as being concrete.

But I think that Herron has introduced something of an inconsistency, since the kind of empiricism to which he appeals-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.

But in all fairness to Herron, a close inspection of his much-cited article, as well as a subsequent one entitled "Piaget for Chemists," reveals absolutely no reference to constructivism, either psychological or social. What these early articles show is that Herron advises chemical educators to make chemistry instruction more concrete, since so many students have apparently not reached the more formal or more abstract stage of reasoning. Herron does finally acknowledge that it might also be an idea to find ways of accelerating the student's entry into the formal level of operation.

> Chemistry, and most of science, is formal by its very nature. Recognizing this we cannot continue to duck our responsibility for the development of formal thought.[8]

But he immediately reverts to the concern shown in his entire paper, namely, the need to make chemical issues more concrete.

> There are some studies which show that education can lead to improvement in formal thinking. We are in the exploratory stage of research in this area but there are consistencies that seem to be emerging. First, the inclusion of concrete experience-i.e. opportunities to actually touch, smell, see, and manipulate materials that would lead to the concept-appears to be important.[9]

No attempt to connect these Paigetian views with any form of constructivism whatsoever has been conducted by Herron in any of his articles in the *Journal of Chemical Education*. Indeed, in all his publications in that journal, I don't believe he has used the word "constructivism" on a single occasion!

The first, and perhaps the only, article in that journal that has attempted to connect the work of Paiget and Herron with constructivism of a psychological kind is one written by George Bodner.[10] In this article, Bodner claims that constructivism is the accepted view among psychologists. Of course, this may be so. It is not for me to comment on this claim. But Bodner also makes a number of rather dismissive remarks on the subject of realism. These claims by Bodner show that there is indeed a gulf between psychological constructivism and philosophical constructivism, for the simple reason that constructivism is by no means the predominant view among phi-

losophers of science. In addition, far from being an abandoned position in philosophy of science, scientific realism continues to flourish, and indeed appears to be the predominant view-opposed only by van Fraassen and his supporters.[11] I also note that Herron himself gives a brief discussion of how his views are supposed to constitute a form of constructivism, but this discussion appeared in a book that was published only in 1995.

The appeal to a nonspecific "constructivism" in the chemical education literature is somewhat ambivalent and continues to cause confusion. The only attempt to express disagreement with full-blown philosophical constructivism that has been made by any chemical educator, that I am aware of, was made by Herron in his book on chemical education, 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.
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> 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.[12]

Herron then adds that

> [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.[13]

Although this word of caution represents a welcome improvement on the writings of other chemical constructivists, it does not go nearly far enough in moderating radical constructivist claims. It addition, it fails to distinguish clearly between philosophical and pedagogical constructivism. 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 that might be drawn to constructivism, and should be made required, rather than optional, reading.

It is also 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 constructivism and relativism. Bodner and colleagues in particular appear to support an unqualified form of relativism, as I argue below, and which I maintain is anti-scientific in spirit.

THE "BEFORE AND AFTER" TREATMENT

Meanwhile, another chemical constructivist gives what can only be described as a simplistic comparison between what he terms "objectivism" and "constructivism" (TABLE 1).[14] Unfortunately, this tendency to present constructivism as though it were a form of weight reduction treatment, complete with "before and after" snapshots, is only too common in chemical education research.

The first of the three statements in TABLE 1 is difficult to interpret as it stands, since the author does not feel the need to qualify what is intended any further. Given

TABLE 1. Distinctions between objectivism and constructivism proposed by Spencer, a chemical constructivist

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.

the scope of the article, namely chemistry and chemical education, I can only presume that the author is referring to scientific truths. The claim appears to be that objectivity is a myth regarding scientific findings whereas, according to the entry in the right-hand column, knowledge of scientific facts is constructed rather than objectively discovered. Needless to say, there may be ways of arguing for the importance of the context of scientific discoveries. After all, the growth of the Science Studies movement attests to such interests among historians and philosophers, but to reduce any such argument to the form of a one-line statement can only be described as an irresponsible move. This is especially so since such articles are intended for consumption by chemical educators who are generally not familiar with the detailed arguments that have been presented in the historical and philosophical literature. It is from chemical education researchers that chemical educators obtain their philosophical education, since they do not generally have the time or inclination to engage with the primary literature in history and philosophy of science.

In fact, to adopt a somewhat naive view, the statement that "truths are independent of the context in which they are observed" is essentially correct, contrary to what the author implies. Indeed, it is a central belief for anyone either practicing or teaching science. If one were to believe the contents of the 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 the year, which is patent nonsense.

Similarly, if the author does not give any further qualification, the statement that "knowledge is constructed" is either plainly incorrect or so uncontroversial as to be superfluous. If the author implies that human preference dictates whether the magnitude of the speed of light is either 3 or 6 or 9×10^8 m/sec, approximately, this is simply 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 Nature itself, then, of course everyone, even the most rabid "objectivist," would probably concur.

The third entry in TABLE 1 is also a gross oversimplification. Unless the author is prepared to qualify the 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 in a vacuum?" then even a radical constructivist would have to concede that there is only

one correct answer. One exception might be the possibility of quoting the velocity to varying degrees of accuracy, but this does not seem to be the kind of thing that the author intends. Indeed, in the particular case of the velocity of light, there is absolutely no possibility of there being more than one response to the question, given the peculiar nature of light.

Alternatively, if the author is thinking of an open-ended question, such as whether Bohr's theory resolved the question of the collapse of the Rutherford atom, then many might respond that there may be more than one answer. As in the previously considered case, one does not need to be a constructivist to accept the entries in the right-hand column 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 think, the height of folly.

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 WITH A VENGEANCE

One of the worst confusions set loose among chemical educators has been the notion of relativism. In an unpublished but widely distributed article, as well as a published one, George Bodner and colleagues leave the reader in no doubt about their own stance on this question.[15] Bodner and colleagues appear to have latched onto a rather idiosyncratic interpretation of relativism that they claim to support. This is what they write:

> 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 [the] 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.[15]

I think this is a simply a misrepresentation of realism as well as relativism. To lump together realism, objectivism, and positivism is misleading, as is the implication that these positions are necessarily outmoded and inappropriate. Objectivism and realism, among the three positions grouped together, remain perfectly viable and are supported by the majority of scientists and philosophers of science. One does not need to be a relativist to accept that observations are influenced by the beliefs and background theories held by the observer. Most objectivists or realists would happily concede these uncontroversial claims regarding scientific knowledge.

Contrary to what Bodner and colleagues 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, to take three random examples, are all equally valid. I maintain that anyone who believes that science is

worth teaching, in preference to these other pursuits, would not claim allegiance to this form of relativism. As far as I know, the only person to ever propose such an outrageous view was the self-proclaimed anarchist of science, Paul Feyerabend,[16] who did so in very similar terms. But even Feyerabend, unlike political anarchists, conceded that he did not intend others to take him seriously.

In the world of analytical philosophy, to be accused of being a relativist is tantamount to being accused of violating rationality itself. If all forms of knowledge are relative, why should one accept relativism as a worthwhile view to adopt? Relativism is simply 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, or that science educators would be prepared to accept such a view. And yet this is precisely what Bodner and colleagues are recommending, in the mistaken belief that it represents a more enlightened and up-to-date philosophical approach to science.

But 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 Harry Collins are now advocating what they term "methodological relativism" as opposed to full-blown, or philosophical, relativism. Collins now holds that

> Methodological relativism says nothing directly 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.[17]

It appears that even the most extreme relativists are trying to distance themselves from full-blown relativism. Meanwhile the chemical educators quoted above still cling to an extreme version of relativism in the belief that it represents an improvement on "objectivism, positivism, and realism."

WHY THROW OUT THE BABY WITH THE BATHWATER?

To do full justice to the question of constructivism in science education would require 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 constructivists, 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. Meanwhile, the claims made by most constructivists in the educational sphere are more modest. They claim that students develop their understanding of science in a constructivist manner. This process is supposed to involve issues such as the preconceptions and misconceptions that students might bring to chemistry classes. One can, of course, accept such views about learning science while at the same time rejecting the more radical philosophical constructivism that claims 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 might have been influenced by all manner of social factors, but mature science is largely free of personal idiosyncrasies.

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. But one suspects that only a small minority of chemical educators-most were trained as chemists-would want to go quite so far. Most educators are understandably attracted to educational constructivism, but overstate their case by drawing support from the more extreme and often anti-scientific writings of philosophical constructivists.

Of course, each individual developing student may have a slightly different initial conception of any particular phenomenon. One might also grant that this conception may be relative to the educational and even sociological background of the individual. But the process of learning science, perhaps more than any other field, involves reaching a position where the student has understood enough of the shared 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 directions. But with respect to concepts such as constructivism and relativism, ideas borrowed from philosophy, chemical constructivists need to make it clear that they are not supporting the same brand of constructivism or relativism in the context of pedagogy. Unfortunately, the present appeal to a nonspecific "constructivism" continues to cause confusion.

SO WHAT?

Some readers may be asking whether any of these philosophical concerns have any real importance in chemical education. I believe that they have great importance, and that chemical education oversimplifies its philosophical content, as I have tried to suggest above. The current approach is sloppy and not conducive to the growth or wider acceptance of chemical education research. It is high time for chemical educators to become more philosophically informed and to begin to address the kinds of issues raised here. Otherwise, they will be providing further ammunition to what scientists generally regard as the "wrong side" of the Science Wars debate.

WHAT SHOULD BE DONE?

What I am recommending is not less use of philosophy in educational issues but more careful use. The obvious remedy is for chemical education researchers to become better acquainted with the philosophical positions to which they appeal in their writings. Secondly, 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. Gone are the days of "heroic philosophy of science," when Popper, Kuhn, or Lakatos would try to pronounce on the nature of the whole of science.[18] It may be because these philosophers attempted to cast their nets too widely that they 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 a Kuhn or Feyerabend, to cite the most popular choices among science educators. Chemistry, 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. But whereas philosophy of chemistry is presently the fastest growing subfield in philosophy of science, it has been almost completely ignored by chemical education researchers, with a few exceptions.[19] Many resources are now available in philosophy of chemistry. All that is required is for chemical educators to begin to draw upon them.[20]

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 ignore recommendations that 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. Now that the situation has begun to change, and philosophy of chemistry is becoming an established discipline, there is no excuse for shoddy philosophical thinking on the part of chemical educators.

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

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