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ABSTRACT

Themes from history and philosophy of chemistry have traditionally been absent in chemistry education. This paper targets the problem of demarcationism within the context of chemistry and alchemy. In so doing, it argues that demarcationism can be an appropriate base for bringing the historical and philosophical aspects of the discipline of chemistry into the learning environment. Demarcation criteria can guide structured knowledge with respect to demarcationism and inform science instruction in guarding against proliferation of pseudoscientific conceptions. It is recommended that these criteria are not taught as such but rather that learning environments provide opportunities for their manifestation and examination. Contains 30 references. (Author)

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SCIENCE OR PSEUDOSCIENCE: DOES SCIENCE EDUCATION DEMARCATE? THE CASE OF CHEMISTRY AND ALCHEMY IN TEACHING*

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ABSTRACT

Themes from history and philosophy of chemistry have traditionally been absent in chemistry education. This paper targets the problem of demarcationism within the context of chemistry and alchemy. In so doing, it argues that demarcationism can be an appropriate base for bringing the historical and philosophical aspects of the discipline of chemistry into the learning environment. Demarcation criteria can guide structured knowledge with respect to demarcationism and inform science instruction in guarding against proliferation of pseudoscientific conceptions. It is recommended that these criteria are not taught as such but rather that learning environments provide opportunities for their manifestation and examination.

INTRODUCTION

One of the philosophical theses advocated in the first chapter of Project 2061's first report, *Science for All Americans*, is demarcationism (AAAS, 1989). Themes such as demarcationism are intended to be developed in science courses within the subject matter of science and not treated as separate content. However, since Project 2061 is meant to be a curriculum framework, it does not contain detailed arguments for the advancement of these theses. Furthermore, as Matthews (1994) puts it, "demarcation statement is underdeveloped and very contentious" (p. 40).

In this paper, I illustrate a framework for demarcationism via a contrast of modern chemistry and pseudoscientific aspects of alchemy. Although history of the discipline of chemistry (Leicester, 1971; Multhauf, 1966; Reichen, 1963) as well as demarcation of science from pseudoscience (Debus, 1992; Radner and Radner, 1982) have been discussed and the use of history in chemistry curriculums have been addressed (Kauffman, 1991), little attention has been given to the study of demarcationism with respect to chemistry teaching. Studying demarcationism within

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the context of chemistry teaching not only elaborates on this important philosophical thesis but also might offer some insight into how students' interest in history and philosophy of chemistry might be stimulated. Many students of chemistry maintain only a minimal interest in history of chemistry and history of chemistry itself, as compared to history of other sciences, has been underemphasized in science education (Brush, 1974).

First, I trace several demarcation criteria proposed by philosophers of science. Demarcationism calls for utilization of these criteria in distinguishing between science and pseudoscience. Second, based on a set of demarcation criteria suggested by the literature and using specific examples of principles as well as practices which attend to these criteria, I point to instances which provide a basis for discussion of demarcationism with respect to chemistry and alchemy. The paper acknowledges that not all practices of alchemy were pseudoscientific but that important contributions have been made by some of its adherents (Dobbs, 1992). The focus here, however, is on the pseudoscientific aspects of alchemy. Hence, the term *alchemy* in this paper denotes a pseudoscience. Used interchangeably are the terms *modern chemistry* and *chemistry* both of which refer to the contemporary field of science. The former is used to emphasize that this science is contemporary whereas the latter avoids the redundancy of the term *modern* where appropriate. Finally, I explore the implications of teaching demarcationism for the design of chemistry learning environments.

DEMARCATIONISM AND DEMARCATION CRITERIA

Demarcation is one of the major philosophical problems which preoccupy philosophers of science (Preston, 1994; Morris, 1987). Demarcationism concerns the important task of distinguishing science from pseudoscience. At a time when our conceptions of science have been challenged (Kuhn, 1962), the task of developing demarcation criteria is not simple. Furthermore, pseudoscience is diverse and complex. Yet, attempts to investigate demarcation criteria can be aimed at sizable, organized endeavors such as mesmerism, astrology and alchemy (Morris, 1987).

In demarcating science from pseudoscience, traditional suggestions make verifiability or falsifiability the decisive criteria (Siitonen, 1984). Although Popper's argument for the falsifiability criterion has been criticized (Preston, 1994), his contribution to the study of demarcation cannot be overlooked. According to Popper, a scientific theory is falsifiable and its validity is its ability to withstand the test of falsification (Popper, 1972). A scientific theory is not validated or invalidated by empirical data. Science involves a process of conjecture, refutation and a new conjecture to overcome the refutation. Every refutation by a new observation results in a more universal theory resulting in the genuine growth of scientific knowledge.

Popper's emphasis on identification of demarcation criteria for what counts as a scientific theory is typical of a discussion of the demarcation problem. That is, demarcationism has traditionally has been addressed exclusively at the level of scientific theories or of cognition (Quay, 1974). However, science and pseudoscience entail more than collected theories or cognitive methodologies. Radner and Radner (1982) suggest that there are *ways of operating* which are found in pseudoscience but not found in science. These have to do with the reasons for proposing an alternative hypothesis, with what are accepted as facts to be explained, with what counts as strong supporting evidence *as well as* with what counts as a theory. The following list summarizes features which Radner and Radner propose as markers of pseudoscience:

Anachronistic thinking
Looking for mysteries
Appeal to myths
The Grab-bag approach to evidence
Irrefutable hypotheses
Argument from spurious similarity
Explanation by scenario
Research by exegesis
Refusal to revise in light of criticism

Although such attributes of pseudoscience have been established, investigation of pseudoscience has generally not been taken seriously. Sarton (1927) states that the historian of science cannot devote much attention to the study of superstition and magic, that is of unreason, because this does not help our understanding of human progress. Magic is essentially unprogressive and conservative; science is essentially progressive. The former goes backwards, the latter forwards. There cannot be much incentive to encompass that which is indefinite and to investigate the history of something which did not develop.

Progress as a demarcation criterion for the sciences is an important one. Quay (1974) attests that "one essential criterion for a field's being a science is that its progress be cumulative, regardless of crises and revolutions from the viewpoint of concrete application" (p.160). In other words, an endeavor is science if it can deductively ground a technology. However, an unwillingness to investigate pseudoscience because it does not progress, overlooks the possibility that pseudoscience can emerge at various times in history with dangerous implications for scientific literacy in society. Today, for example, pseudoscience is not extinct (Park, 1995). There exist adherents of parapsychology, biorhythm and creationism. Serious consideration of demarcationism and demarcation criteria would be facilitated by our informed judgments of pseudoscience *as well as* science. I would argue that science itself would be more meaningful for learners of science if it is articulated with respect to and differentiated from pseudoscience.

TEACHING DEMARCATIONISM WITHIN THE CONTEXT OF CHEMISTRY AND ALCHEMY

Leisten (1994), in his defense of teaching the atomic theory to elementary school children, questions what we teach of chemistry in our schools today:

> "Getting potash from bananas/.../ or butyl acetate from over-ripe ones/.../ adds zest to a balanced course, but if the pupils are insecure with atoms and molecules they will perform such operations in the dark, as close to alchemy as to science" (p. 552).

Indeed, the danger of fostering pseudoscientific themes in chemistry lessons needs serious consideration. However, this danger is not necessarily pertinent only to the study of the atomic theory or chemistry content as such. An examination of and engagement in the process of science has traditionally been lacking in science education (Matthews, 1994). Science instruction devoid of activities, methods and processes of science is bound to fail in scaffolding scientific literacy (Miller, 1983) and could potentially result in the proliferation of pseudoscientific conceptions. In this sense, inclusion in chemistry instruction of the historical, philosophical and social aspects of chemistry not only can contribute to interesting learning environments but also might assist students in constructing a richer understanding of science.

Teaching demarcationism within the context of chemistry and alchemy requires careful examination of these domains. However, my concern here is not to lay them out in all their complexities. Science and pseudoscience cannot be captured in a few general phrases. However, it is necessary to offer brief accounts on what chemistry and alchemy are generally regarded to entail if I am to consider them with respect to demarcationism. The usual conception of the scientific method is that it consists of gathering data, formulating a hypothesis to explain the data and testing the hypothesis by experiment. As it stands, this description is not sufficient to distinguish science from pseudoscience. The scientific method operates within the actual subject matter of the sciences. One must examine scientific explanations in the context of a particular field of science in order to understand them (Hempel and Oppenheimer, 1948). Chemistry today is the science of molecules and their transformations (Hoffmann & Torrence, 1993). Explanations in chemistry are based on our knowledge of atoms and molecules established by sophisticated methodology such as mass spectroscopy and nuclear magnetic resonance.

Generally, alchemy is described as the search for formulas that would turn base metal to gold (Debus, 1992; Multhauf, 1966; Federmann, 1964; Read, 1947). "It was the never ending search for the Philosopher's Stone and the Elixir of Life, those mystical agents that would give the possessor of their secrets the touch of Midas and everlasting youth" (Reichen, 1963, p.20). Alchemists believed that through the transformation of base metal into gold they would demonstrate the essential unity of the world and all that it contained. In their minds, their craft was part of the struggle of all things toward perfection. They connected the Christian idea of Eden with the Greek doctrine of a golden age when all metal was gold and all people were pure and innocent. If only base metals could be returned to their pristine state, then people could also relive the days of their innocence. In a world dominated by theology, mysticism, cultism and conscience of original sin, the alchemists' dream was a vision of salvation.

Comparison of chemistry and alchemy in teaching not only provides an opportunity for studying demarcationism but also attends to domain-specificity of scientific reasoning. Since scientific reasoning occurs with domain-specific knowledge (Voss, Wiley & Carretero, 1995; Glaser, 1984), declarative knowledge of a field of science has to be taught. However, declarative knowledge needs to be coupled with procedural knowledge of the domain. That is, learning in science and the development of scientific reasoning involves the restructuring of both declarative and procedural knowledge. Glaser (1994), in a keynote address delivered at the 23rd International Congress of Applied Psychology, offers a set of seven related emerging principles of instruction derived from learning theory that can be used to shape learning environments. One principle concerns nature of structured knowledge:

> "Instruction should foster increasingly articulated conceptual structures that enable inference and reasoning in various domains of knowledge and skill. Education that teaches isolated memorization of facts and definitions of concepts will not accomplish this purpose" (p. 17).

Demarcationism is a broad and debated issue. In order to be presented within the teaching context, it needs to be defined by some content. Demarcation criteria can guide the structuring of knowledge towards this end. However, such criteria are not exhaustive or final. Elaboration of demarcation criteria with principles and practices of chemistry and alchemy can begin to show how demarcationism can be approached in chemistry instruction. Trace of demarcation criteria in this fashion is not meant to decontextualize mentioned concepts. This approach only serves to capture and exemplify *what* can be examined with respect to demarcation criteria. Finally, articulation of demarcationism in-and-of itself does not speak to *how* it can be implemented within the teaching environment. Yet, this articulation is an essential step in proposing ways to bring demarcationism into the classroom.

FRAMEWORK OF DEMARCATION CRITERIA FOR DISTINGUISHING MODERN CHEMISTRY FROM ALCHEMY

Marks of pseudoscience as summarized by Radner and Rander (1982) can be traced in examining alchemy as a pseudoscience. However, since demarcationism is to be developed within science instruction, it is crucial that elements of science can be utilized within the learning environment both to describe science and distinguish it from pseudoscience. In this sense, criteria which target hypotheses, arguments, theories as well as social practices in science become central to the discussion of demarcationism.

These criteria follow from and are consistent with those proposed by philosophers of science (Morris, 1987; Siitonen, 1984; Popper, 1972).

Any hypothesis that purports to be scientific must be *refutable*. By being possible to refute a scientific hypothesis, I mean that there must be some circumstance which if encountered, would count against this hypothesis. However, refutability does not imply that the hypothesis is or will actually ever be refuted. From the point of view of modern chemistry, hypotheses such as "Chemical reactions of metals are similar to those of non-metals" and "Chemical reactions of metals are different from those of non-metals" are refutable even though only the former is refuted. In contrast, alchemists often delighted in irrefutable hypotheses. No explanation was allowed to count against what they said and so no fact would ever prove them wrong. Nothing was said about the material world in the first place. Those alchemists who claimed to have discovered the secret of the Philosopher's Stone, for example, replied with insults or evasions when asked to share their knowledge in light of disconfirming evidence. "You poor fool, are you really so naive as to think that we would teach you the most magnificent mystery in creation?" (Reichen, 1963, p.27) was a typical response which made reference to alchemists' affinity for irrefutable hypotheses.

The question of whether a hypothesis is *consistent with established scientific principles* is an important one in science. A new proposal often leads to less elaborate argumentation if it is compatible with current science than if it is revolutionary. Synthesis of new chemicals today, for instance, presupposes the atomic theory. Alchemists' claims for turning base metal into gold were not based on what was known of metals at the time. Alchemists sought to mystify metals, not to explain them. A common deception in Medieval Europe was to take a nail made half of gold and half of iron and cover it with a black substance. The gold portion was dipped into a liquid which washed away the covering and revealed the metal underneath (Federmann, 1964).

Chemists often employ *arguments from similarity or analogy*. They acknowledge that the analogy must be specified in detail, noting exactly the similarities and differences. Valid application of the analogy from one area to another is crucial. For example, in biochemistry the structure and function of enzymes are often described in relation to a lock-and-key model. However, chemists do not argue that a new proposal is valid *because* it is analogous to something similar. In the enzyme example, the analogy serves to help us understand the biochemistry involved. It does not dictate what the biochemistry should be. Many alchemists who adhered to discovery of transmutation as a means to salvation did rely on Biblical analogies in their efforts to unravel the mysteries of alchemy (Reichen, 1963). However, in so doing, they posited a particular condition, an analogy in order to justify their claims.

In every scientific theory, there is an aspect of *generality* (Hempel and Oppenheimer, 1948). This aspect is indispensable, for without it a scientific theory has no explanatory power. To explain a phenomenon scientifically is to show how it follows from general laws. For example, evaporation of liquids can be accounted for by the kinetic theory. This notion of generality based on natural laws was absent in the thinking of alchemists. Those who attempted to tackle the question of generality often did so in pseudoscientific terms. Among the early and most famous practitioners of alchemy was Zosimos (Reichen, 1963). Zosimos based his work on the principle for the oneness of all matter. (This idea, which contains a considerable element of truth, was fundamental to all alchemical philosophy.) An early experiment by Zosimos illustrates the philosophy of transmutation and alludes not only to the discrepancy in the aspect of generality in alchemical theories but also points to the absence of reference to general laws. "Heat ordinary water in an open vessel. When it boils, it is dissipated in the air and leaves a powder, white sediment at the bottom of the vessel. Conclusion: water changes into air and earth" (Reichen, 1963, p.20). Other alchemists adhered to this explanation for more than a thousand years until the disappearance of water could be accounted for in a truly scientific manner.

Alchemists often prided themselves in never having shown to be wrong. The quest for salvation via alchemy, for instance, could never be proven wrong. The claim that alchemy was instrumental in salvation would never be needed to be taken back or revised since it was vacuous, it didn't say anything in the first place. However, immunity to *criticism* is no measure of success in science (Radner and Radner, 1982). The magnitude of criticism and controversy that a new proposal can stimulate in the contemporary scientific community is reflected in the debate over cold fusion. In contrast, alchemists often replied criticisms but they hardly ever revised their claims in light of these criticisms Federmann, 1964). Their vision of debate was not a mechanism for scientific progress; it was a rhetorical contest.

The collection of scientific writings which report results of research in a given area is often referred to as the *literature*. A work in chemistry functions only by virtue of its content: the data reported and the arguments presented. The individual style of work has no scientific significance. In the hands of alchemists, however, science was dressed as a secular substitute for sacred literature (Dobbs, 1992). A typical alchemical passage illustrates the theological and psychological underpinnings of alchemical writings:

> "But when we marry the crowned king with the red daughter, she will conceive a son in the gentle fire, and shall nourish him through our fire.... Then he is transformed, and his tincture remains red as flesh. Our son of royal birth takes his tincture from the fire, and death, darkness, and the waters flee away. The dragon shuns the light of the sun, and out dead son shall live. The king shall come forth from the fire and rejoice in the marriage. The hidden things shall be disclosed, and the virgin's milk be whitened. The son is become a warrior fire and surpassed the tincture, for he himself is the treasure" (Hoffmann & Torrence, 1993, p. 80).

So was the symbolism in the language of alchemy. Tales alluded to chemical transformations. The suspicious philosophical basis for maturation and transformation of chemical substances, and in fact, the alchemists themselves, merged with myth and fiction, resulting in the alchemical literature.

One important aspect of science is that it can yield a *technology* (Quay, 1974). Today, chemistry impacts numerous technologies such as food technology and biotechnology. Beginning with the fifteenth century, the practice of alchemy began to move away from the search fo. the Philosopher's Stone to more practical and reasonable goals (Multhauf, 1966). More effort was exerted on the healing arts through the new science of iatrochemistry or medicinal chemistry. At the same time, a growing emphasis was placed on the practical applications of metallurgy rather than the transmutation of base metal into gold. However, emergence of new fields such as iatrochemistry and metallurgy was not a consequence of alchemical practices. The chief exemplar of this *new scientific approach* was the early seventeenth century Flemish chemist, physician and physicist Jan Baptista van Helmont who is regarded to represent, more than any other individual, the transition of chemistry from alchemy to science (Reichen, 1963).

The mentioned demarcation criteria span various aspects of science: from arguments in science to attitudes of scientists although they should not by any means be regarded as being exclusive of other dimensions of science. Initial consideration of what can form a framework for demarcationism within chemistry instruction calls for a comprehensive account of the problem, such as the one presented here.

IMPLEMENTATION OF DEMARCATIONISM: IMPLICATIONS FOR THE CONTEXT OF LEARNING

Although demarcation criteria provide a framework for declarative knowledge in teaching and learning, treatise of demarcationism within the educational context is not bound by content alone. Glaser's (1994) principles of instruction derived from learning theory point to the importance of active use of knowledge in meaningful contexts:

> "Learning activities must emphasize the acquisition of knowledge but this information must be connected with the conditions of its use and procedures for its applicability. . . . School learning activities must be contextualized and situated so that the goals of the enterprise are apparent to the participants" (p. 19).

Chemistry learning environments need to be designed such that opportunities are present for manifestation, exploration and evaluation of demarcation criteria. Curriculum and instruction models that are grounded in cognitive psychological theories necessitate a consistency with the other fundamental practices that characterize schools and schooling. For instance, assessment and feedback that students receive ought to be consonant with learning goals and outcomes (Messick, 1987). Fredericksen and Collins (1989) refer to this match between curriculum, instruction and assessment as *systemic validity*.

Science education that targets establishment of systemic validity has to be innovative (Erduran & Duschl, 1995). Formats such as portfolios for instance, challenge our traditional notions of classroom cultures (Duschl & Gitomer, 1993). Bringing into the science classroom today, an endeavor such as alchemy, which belongs to the past, calls for new visions in curriculum, instruction and assessment. Understanding alchemy would involve more than reading history textbooks on chemistry. Investigation of this pseudoscience in the learning context requires that there are chances for students to experience its practice via social participation. Glaser's (1994) principle on social participation and social cognition reflects on Vygotsky's (1978) theory of cognitive development which emphasizes the significance of culture in learning:

> "The social display and social modeling of cognitive competence through group participations is a pervasive mechanism for the internalizations and acquisition of knowledge and skill in individuals. Learning environments that involve dialogue with teachers and between peers provide opportunities for learners to share, critique, think with, and add to a common knowledge base" (p. 19).

Beginning to consider the social dimension of learning alchemy is no simple matter. Our knowledge of alchemy is based on historical research. Often there is ground for speculation and uncertainty in its proper characterization. Furthermore, alchemy developed independently by different cultures such as Chinese, Indian, Egyptian and Greek cultures (Leicester, 1971). Elements of these cultures cannot be captured in arguments alone. It is crucial that students grasp the identities, the roles of alchemists within their cultural settings as well as understand the philosophy and practice of alchemy in history.

Learning the culture of alchemy implies that learning environments can reflect the essence of alchemy. Yet, there are considerable religious, psychological and mystical undertones of alchemy (Hoffmann and Torrence, 1993) which may seem out of place in science instruction. I argue that a rich conceptual understanding of demarcationism with respect to modern chemistry and alchemy would necessitate that boundaries between modern chemistry, history of chemistry, art, fiction and drama are blurred. However, a merger of traditionally distinct disciplines is neither simple theoretically nor is it viable practically in many educational settings today. Nevertheless, at a time when the demand for scientific literacy in a global market is increasing, it is vital that we begin to embrace new ideas in order to provide the occasion for students of science to learn.

CONCLUSIONS

In conclusion, I argue that demarcationism not only provides a valuable context for rich conceptual understanding of chemistry (via elucidation of what makes chemistry a science) but also brings together the historical and philosophical dimensions of this science thereby reinforcing this understanding. Articulation of *what* to teach of demarcationism in a specific subject matter is an early but essential and crucial precursor to *how* to implement effective teaching with respect to this thesis.

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