THE PLACE OF PHILOSOPHY OF CHEMISTRY IN REDUCING CHEMICAL MISCONCEPTIONS

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ABSTRACT
This paper aims to forward a framework that can give an insight how philosophy of chemistry plays a role in reducing chemical misconceptions and be incorporated in the teaching-learning process of chemistry. It is concluded that epistemological explanations and representations specific to the macroscopic, microscopic and symbolic levels of chemistry are important elements for instructional representations to consider in the teaching-learning process of chemistry. *[AJCE, 3(2), June 2013]*

INTRODUCTION

There is a growing interest in the philosophy of chemistry and how it influences chemistry education. In fact, as Schummer (1) argues that:

> *The time of complaining about the neglect of the philosophy of chemistry is over now. With more than 700 papers and about 40 monographs and collections since 1990, philosophy of chemistry is one of the most rapidly growing fields of philosophy. Perhaps too rapidly, as it has become arduous for insiders to keep up-todate, troublesome for newcomers to approach the field and virtually impossible for outsiders to survey the main ideas* (p.19).

Our intent in this paper is therefore not to discuss the neglect of philosophy of chemistry as was the case in early 1990s but to try to indicate the place of chemistry in challenging misconceptions in Chemistry teaching and learning.

Academics in the field argue that Chemistry can be "conceived as a 'phenomenological' science that only describes 'phenomena' which are apparent facts (2-3). This 'phenomena' is divided into physical and chemical phenomena (4). The physical phenomenon explains changes that involves from one form or state of substances to another form while the chemical phenomenon explains chemical change which involves a formation of new substances (4). Chemists engage in chemical phenomena through experimentation and explore the essential nature of chemistry to revise or develop their theories (3, 5).

It has been noted that (6) the philosophy of chemistry is a pragmatic and experimental science that combines both process philosophy and substance philosophy. Substance philosophy gives priority to entities or substances, and it explains that entities are permanent whereas process philosophy gives priority to the temporal state of entities and it asserts that only changes are permanent (6). Therefore, according to pragmatic philosophy of chemistry that combines both substance and process philosophy, chemistry characterizes and classifies chemical entities and substances and also describes changes that occur on chemical entities. It is concerned with characterizing substances, i.e. substance philosophy, and changes, i.e. process philosophy (6).

In sum, epistemological (philosophical) explanations and representations of chemistry argue that characterization of substances and changes in chemistry are made at macroscopic, microscopic and symbolic levels. It has been stated that “to meet students at their level and avoid misconceptions, chemistry educators are advised to pay careful attention to how these thinking levels are introduced” (7, p.50). Accordingly, instructional practices in chemistry have to be founded on these level-specific explanations and representations; otherwise students may face learning difficulties or develop chemical misconceptions.

A study (8) reported that creating association between microscopic model and macroscopic events were some sources of students’ learning difficulties and misunderstandings. Recently, it has been demonstrated (9) that some of the chemical misconceptions held by students in schools are related to the mixing of explanations and pedagogical representations of the macroscopic level chemical properties onto microscopic or symbolic chemical properties. Therefore, this paper attempts to forward a framework that can give an insight into how philosophy of chemistry plays a role in reducing chemical misconceptions and be incorporated in the teaching-learning process of chemistry. In doing so, the paper intends to initiate further discussions among chemistry educators in Africa and the world at large on the philosophy of chemistry and its pedagogical implications for teaching and learning chemistry.

CHEMICAL EXPLANATIONS, REPRESENTATIONS AND THEIR INFLUENCE ON PEDAGOGY OF CHEMISTRY

One of the epistemological arguments for the independence of chemistry is the theme of supervenience. Supervenience states that the properties of matter at macroscopic and microscopic level of chemistry have an asymmetric relationship (10-11). It means that chemical explanations about the properties of matter at macroscopic level are not exactly applicable to explain properties at its microscopic levels. For instance, graphite and diamond are constituted from carbon atoms, but explanations given about the properties of graphite or diamond couldn't be applicable to explain the properties of carbon atoms. Hence, characterizing class of chemical identities (substances) and descriptions of chemical reactions or changes (process) should be made at three different representational levels (i.e. macroscopic, microscopic and symbolic levels). And the characteristics of chemical entities and temporal (reactions) nature of chemistry at each representational levels needs to be taught using pedagogy that go along with the nature of chemical explanations given to the respective representational levels.

It has been stated that (2) chemical knowledge or explanations are level specific. It means that chemical knowledge or explanation at macroscopic level is specific to this level, or it is not transferable to microscopic and symbolic level. For instance, explanation given to copper wire is specific to copper wire, it is not applicable to explain copper atom. The property of copper wire (macroscopic level) is malleable and ductile, but copper atom (microscopic level) is not.

Another example is that the identity of water in everyday life, such as melting and boiling point, color, odor, and shape are some of its macroscopic properties. But its chemical identities (properties) at microscopic level (i.e. water molecule and its geometry, the nature of the atoms and bonds between these atoms) cannot be concluded from the observable (macroscopic) properties of water. Water molecule (H_2O) has a V-shape and forms a tetrahedral arrangement of water as a bulk system. Despite the asymmetric relationship between properties of identities of water molecule, H_2O (g) and water, H_2O (l) in a container, the macroscopic properties of water can be explained by its microscopic identities. This suggests that the instructional presentations used to teach water at the two levels should be different but carefully interconnected.

In general, although explanations at the macroscopic, microscopic and symbolic levels of chemistry are unanimously converged in explaining chemical phenomenon (12), the asymmetric relationship between the properties of macroscopic system and microscopic identity is maintained. Therefore, the epistemic explanations of the properties of matter in the teaching-learning process of chemistry have to be level specific. And the pedagogy of teaching chemical explanations has to be level specific; otherwise, it would be source of some chemical misconceptions.

Moreover, it is argued that knowledge about the world has a representational nature (13) and it has an epistemological origin. Chemistry knowledge has a unique nature and ways of representations. To this end, chemical phenomena are understood through macroscopic, submicroscopic and symbolic levels of chemical representations. This in turn affects the structure of modern chemistry (12).

However, the use of the same symbolic representations to both macroscopic and microscopic levels of chemical realities may become possible sources of chemical misconceptions. For instance, if we consider the burning piece of copper wire in a laboratory, we can have the following pedagogical representations:

a)	$2Cu$ (solid [s]), red-brown) + O_2 (gaseous [g], colorless) $\longrightarrow$ $2CuO$ (solid, black)
b)	Copper (s, red-brown), + Oxygen (g, colorless) $\longrightarrow$ Copper oxide (s, black)

Using the same pedagogical representations for both macroscopic and microscopic levels used either in (a) or (b) form may lead students to develop erroneous conclusion about the behavior of copper wire and copper atom. Because, students may think that color and state of copper wire and copper atom are the same while they are different. To reduce such sources of misconceptions, therefore, pedagogical representations and descriptions have to be specific to macroscopic and microscopic levels of chemical realities. And the representations used for copper wire and copper atom should not be the same.

In a study it has been reported that students argue that water disintegrates into H_2(g) and O_2(g) when it boils (14). This students' explanation about the boiling of water seems linked to their understanding about the behavior of gases, which are not observable directly. This misconception is likely to be developed due to failure to show the interconnection between the bulk H_2O (l) and the molecule H_2O (g). However, if the teaching of the nature of water both at macroscopic and microscopic level uses distinct ways of representation, and show the relation and how molecule H_2O (g) aggregates to form the bulk water, students couldn't develop such a misconception.

On top of representational nature of chemistry, the object of study, theories and language of chemistry education are defined by the ontological, epistemological and methodological views of chemistry. It has been stated that "the philosophy of chemistry addresses the scope of the phenomena that fall within the remit of chemistry, with the ontology of the entities of which those phenomena are thought to consist, and with matters of epistemology, the grounds of belief on which such knowledge rests" (15, p.213). These philosophical views, which determine the scope and nature of chemistry highly influences the 21st chemistry education. In this connection Scerri (16) states that the philosophy of chemistry has an important influence on the teaching of chemistry and chemistry education in general.

Philosophy of chemistry is also influencing the thinking of modern chemical educators and the structure of modern chemistry. It is becoming a new pedagogical resource of chemistry teaching (2, 17). Some of the influential chemistry education metaphors have a philosophical origin. Mahaffy's tetrahedral metaphor of chemistry education (7, 18), Johnstone's Chemistry Triangle (19-21) and Jensen's logical structure of chemistry (22) are some of the major chemical education models to some extent influenced by the philosophy of chemistry.

THE IMPACT OF LEVEL SPECIFIC EXPLANATIONS AND REPRESENTATIONS OF CHEMISTRY ON STUDENTS' UNDERSTANDING

Erduran (10) states that one of the fundamental ways of thinking in chemistry is "the interplay of the microscopic, symbolic and macroscopic levels". Thus, understanding chemistry involves connecting the macro, micro and symbolic world of chemistry (21, 23-24). If the interplay between the microscopic and macroscopic level of chemistry is not properly taught using best suit pedagogy of chemistry, students' may develop a wrong understanding or misconception.

For instance, in connection to the relation between microscopic and macroscopic world of chemistry, it is noted that "all properties of organic molecules- physical, chemical, biological, and technological-depend on their chemical structure and vary with it in a systematic way" and "most physical properties of organic compounds depend functionally upon the number, kind, and structural arrangement of the atoms in the molecule. The number and kind of atoms are both constant in isomers, and hence, the differences in their physical properties are due to structural relationships” (25, p.5715). This tells us that the macroscopic and microscopic identities of chemical substances are not identical. In other words, the chemical and physical properties of the macroscopic system are not exactly alike to the microscopic identities of the system. Chemical misconception about the scientific understanding of chemical substances could arise from lack of clear and distinct understanding between the macroscopic and microscopic identities and their respective chemical representations. Therefore, the descriptions and pedagogical representations need to be carefully designed not to allow the transfer of understanding of macroscopic properties of chemical phenomena onto understanding of its constituents (microscopic properties).

Accordingly, the instructional representations of the bulk (macroscopic system) have to be presented in a distinct way which shows the microscopic identities (the kind, and number) and how they are arranged in order to form the bulk. The instructional representations of microscopic identities and their constituents have to be distinct from the macroscopic system. If the macroscopic system and microscopic identities are represented with the same kind of symbols and pedagogical representations, students may fail to develop correct scientific understanding and fail to predict or explain macroscopic properties from microscopic identities. This might lead to the transfer of observation of macroscopic system to the microscopic identity which could results in students’ misconception.

Chemical misconceptions are possibly resulted from the mixing up of one level of chemical explanations onto the other. Most of the time studies show that the transfer of chemical explanations from one level to the other is common features of many chemical misconceptions.

Chemical explanations such as substances expand when they are heated and the volume of gases is related to pressure are examples of explanations for macroscopic level properties of matter. Based on these assertions, for example, “molecules expand when they are heated” and “pressure affects the shape of a molecule” were among some of the misconceptions held by students (14). Such misconceptions were resulted due to the transfer of explanations given to macroscopic properties on to microscopic identities. It is also noted (26) that students tend to assume/surmise phase changes occurring at the microscopic level from their observations of macroscopic changes of a substance.

There have been misconception reports which state that students understand that the boiling of liquid H_2O (l) results into bubbles composed of air or H_2 or O_2 (14). This misconception is mainly linked to the application of macroscopic view of ideas that explain breaking the bulk material involves disintegrating the whole into its constituent parts. It tends to imply that if students think that the constituents of both liquid water and water molecule are the same, then they will apply the same explanations to both of them. Such lack of distinctions in students understanding about the constituents of liquid water and water molecule is a likely reason for their justification that boiling of H_2O (l) resulted into bubbles composed of H_2 or O_2. Moreover, students’ understanding of H_2 and O_2 as composition of air can also has an interfering effect on their understanding of boiled water.

In conclusion, failure to show the distinct nature and interconnections of chemical explanations and representations for the macroscopic, microscopic and symbolic level might become one major source of chemical misconceptions since such failure is inherently linked to the nature of chemistry.

PEDAGOGICAL IMPLICATIONS OF THE PHILOSOPHY OF CHEMISTRY TO REDUCE MISCONCEPTIONS

The philosophy of chemistry is an important tool to characterize chemical knowledge and its representational nature. It can be good instructional tool to describe and connect chemical knowledge at macroscopic, microscopic and symbolic levels. The pedagogical explanations and representations have to be specific to each level of chemical realities and carefully design to show the interconnection among the levels. Therefore, the chemical misconceptions that could result from the interference of knowledge from explanations about one representational level or explanation onto the other could be reduced if the philosophy of chemistry and its pedagogical influences are incorporated into teacher education program as part of pedagogical knowledge in pedagogical content knowledge (PCK) for chemistry education.

Given the fact that we are now living in the 21st century where the century's skills are highly related to technology, it would be important to incorporate the philosophy of chemistry and its pedagogical influences into teacher education program as part of technological pedagogical content knowledge (TPCK). Such an approach is already conceptualized (27) and attempts are under process to fully design and implement the approach in Chemistry.

What are your views in relation to the philosophy of chemistry and its influence on teaching and learning of chemistry in particular and chemistry education in general? Please share your views as feature articles, letter to the Editor, etc in our Journal (African Journal of Chemical Education, AJCE).

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