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The « amount of substance » and its unit the « mole » Rita Khanfour-Armalé

Introduction

The 'mole' unit of the amount of substance is one of the fundamental concepts in quantitative chemistry. The "amount of substance" is a concept that has been a frequent subject of discussion among science education researchers (Staver and Lumpe, 1993; Furió et al., 2000). However, previous research has shown that because of its abstract nature and the anomalous evolution of the definition in scientific history, the mole is generally acknowledged to be one of the most perplexing concepts in chemistry teaching and learning (Fang, 2011).

The concept of amount of substance and mole present difficulties to students because they are abstract (Dierks 1981) and there is a lack of understanding of the microscopic and macroscopic scales (Claesgens & Stacy 2003). Common misconceptions include defining the mole as Avogadro's number (Claesgens & Stacy 2003), as a mass or as a property of a molecule. Students have no context for the mole (Gorin 1994) and there is a diversity of language used to establish the concept of amount of substance¹ and this causes problems for many students. The teachers have the notion that the 'mole' unit is introduced as a unit of 'chemical mass' that serves to count the elementary entities of different substances. Furió et al.(2000) found that teachers themselves were confused about the meaning of "amount of substance". They have an operational form of teaching resulted from a non-problematic vision of science which gives students a decontextualized meaning. Pekdag and Azizoglu (2013) found that there are semantic mistakes in the presentation of the amount of substance and the mole concept in chemistry textbooks.

To understand these difficulties, it would be useful to provide a brief review of the historical development of the amount of substance and mole concepts. From the 20th century, the worldwide acceptance of the atomic-molecular theory of matter to interpret chemical changes eventually led the scientific community to adopt amount of substance as a fundamental quantity and to define the mole as its unit (Fang, 2011). At first glance, the SI definition of a mole ² accords with the atomistic paradigm because it refers to a certain number of elementary particles. However this number is actually defined by a specific mass of a specific substance (12 g of ¹²C), an idea originally attached to the equivalentist paradigm. The attempt to make two apparently incompatible paradigms, the equivalentist and the atomistic paradigm, converge helped the scientific community to reach agreement on what the word "mole" actually means. However, the consequences of the convergence were that multiple meanings and conceptual contradictions resulting from the historical evolution of the mole have become sedimented in the SI definition of the mole.

The amount of substance connects the macro-world with the micro-world. Learning the amount of substance concept meaningfully and in-depth is closely dependent on how well teachers are able to present the concept in a manner that creates meaningful relationships between the macroscopic, the

¹ In Latin, the word moles means "big mass"; adding the suffix -cula converts the word to the term molecula, meaning "small and tiny". The term molar, mean large or macroscopic mass, the opposite of the term "molecular mass".

² A mole is the amount of substance of a system which contains as many elementary entities as there are carbon atoms in 0.012 Kg of ¹²C. its symbol is "mol". The elementary entity must be specified. When the mole is used, the elementary entities must be specified and may be atoms, molecules, ions, electrons, other particles, or specified groups of such particles. The mole is a base unit of the International System of Units (BIPM, 2006, p. 115).

microscopic and the symbolic level (Pekdag and Azizoglu, 2013). Rare French study about these two concepts has been encountered in chemical education; however Laugier and Dumon (2004) have attempted to elucidate the nature of the difficulties faced by high school students and undergraduate degree courses for understanding and mobilization of the concepts of mole and amount of substance in stoichiometry problems. I'm interested about the way the mole concept is presented in classrooms.

Method

I used for this pilot study two videos³ of 2 teachers presenting and teaching the amount of substance and the mole in their classes. Videos helped us to transcribe the interactions between teachers and students. The two teachers had been teaching for 4 and 19 years. They use the same teaching sequence designed and improved during meetings between these teachers and SESAMES group. In the postlab, the teachers take back the responsibility of organizing the knowledge after having let his/her students be autonomous during the labwork. They give to students a document with a summary of the knowledge to be learned designed and improved by the same group.

The semantic mistakes (Pekdag and Azizoglu, 2013) are classified under three different sub-groups: "missing concept" was defined as "a concept that is absent at the macroscopic, microscopic or symbolic level. The mismatching concept was defined as "using the amount of substance concept as equivalent to the concepts of mass, molar mass, number of particles or molar volume". And Inappropriate expression was defined as "the observed incorrect usage of a microscopic level concept in place of a macroscopic level concept or vice versa".

Fang and al. (2014) use the expression "the mole concept" and proposed a concept map (Figure 1). They point out explicitly that the key to making meaning of the mole is to relate the mole concept to the atomic-molecular concept from both the number and the mass aspect. The number aspect (linking idea 1) provides a theoretical (atomic) view of chemical reactions to be the right amounts of chemicals involved in a chemical reaction. The mass aspect in terms of the connection between molar mass and relative atomic mass (linking idea 2) explains why the molar mass of a substance has the same numerical value as its relative atomic or molecular mass, and which rationalizes practical laboratory work.

In one hand, the analysis of the summary document is based on the semantic mistakes. In the other hand, based on the concept map linking idea were searched in the postlab session.

Results

The analysis shows that the summary document (4 pages) use the correct expression. I found just 1 inappropriate expression and 1 mismatching concept. The analysis of the videos shows that the mole concept was defined and conceptualized with emphasis on the mole as a number. Neither the SI definition in terms of 12 grams of ^{12}C (the mass aspect of linking idea 1) nor the connection between molar mass and relative atomic mass (linking idea 2) was explicitly explained. The two teachers adopted same strategies in the lessons and the presentation was very similar.

Discussion and conclusion

³ Taked for another research

Despite the use of the sequence and the summary text designed by the group, teachers fail to take full advantage. As suggested by Fang (2011) because of the differences in how the mole concept has been conceptualized between the scientific and the educational domains, through their training, chemists and teachers learn to use the mole concept as a 'tool'. Their associated conceptual understanding becomes so ingrained that its importance goes unrecognized. As a consequence, it seems that the teachers' lack of explicit awareness of the underlying concepts resulted in some ambiguities in their classroom instruction.

Pekdag and Azizoglu (2014) proposed three models for the correct scientific representation of the mole. With the model 1 it is not semantically correct to have knowledge at the macroscopic level (element, compound, etc.) immediately follow the term mole that defines the number of particles. Model 2, can be applied to expressions where physical quantities such as mass and volume are being used. Model 3 can be used in representations in which the amount of substance concept is associated with the number of particles.

This paper reports the findings from a content analysis relating to the concept of the mole. This content analysis formed a part of a project that will investigate the process of teaching and learning the mole concept in secondary classrooms.

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