Concept Maps: Making Learning Meaningful
Proc. of Fourth Int. Conference on Concept Mapping
Viña del Mar, Chile, 2010

RELATIONS BETWEEN MACROSCOPIC AND MICROSCOPIC CHEMICAL CONCEPTS: AN INVESTIGATION OF UNDERGRADUATE CHEMISTRY STUDENTS´ CONCEPTIONS

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Abstract. This study analyzes an activity aimed to promote students' reflection concerning their conceptions about the nature and the organization of chemistry. Third year undergraduate students at the University of São Paulo (Brazil) were asked to produce concept maps expressing the relations between the main concepts studied in the different disciplines of chemistry undergraduate curriculum. Analysis criteria focused on the more important concepts around which the maps are conceived and how students established links and connections between macro and microscopic concepts. The obtained results showed that in general students select a "starting point" or a "central concept" around which the organization of the chemical concepts is expressed suggesting conceptions for chemistry that can be described either as more "static" or more "dynamic". While some students place structure - described in terms of atoms and molecules - at the heart of chemical knowledge, others emphasize to the concept of "chemical reactions, expressing the dynamic relationship between substances as the most important aspect of chemistry. The prevalent observed tendency is structuring chemistry in an ontological approach: at the base the simplest and most elementary entities (atoms), then their combinations (molecules), and then the interactions between these, etc. Much less adopted for the structuring of the concepts was phenomenological perspective, which considers as starting points the concepts which are more concrete and more directly observable, followed by the more abstract concepts that were constructed to explain the "sensitive" world.

1 Introduction

On one hand, chemistry developed by the manipulation of macroscopic quantities of matter. On the other hand, throughout the 19th and 20th centuries, models were developed to describe the (sub)microscopic world and to explain the observable macroscopic phenomena. Thus, chemistry presents an important characteristic of promoting a dialogue between the macroscopic and the (sub)microscopic dimensions. Considering more recent developments of research in chemistry, an increased emphasis in its character as a science that handles (sub)microscopic structures can be noticed, and chemistry is being described as "molecular engineering" or "nanotechnology" (Greenberg, 2009).

Considering the practitioners of chemistry and what are their educational needs, it is important that the undergraduate chemistry student acquires a vision of that considers the dialogue between the three learning levels (the symbolic, macroscopic and sub-microscopic, or molecular) that are needed for students to make sense of chemistry, and also the fundamental changes in the contours of chemistry as defined by its new frontiers and interfaces (Mahaffy, 2004). In the case of chemistry-student teachers, the educational goals for high school chemistry relate largely to the adequate establishment of relations between the macroscopic properties and scientific models that explain such properties. Within this context, we consider relevant to analyze, in a qualitative way, visions of undergraduate chemistry students as regard the relations between macro and microscopic aspects of matter, as expressed in concept maps and texts.

2 Methods

This study analyzes an activity aimed to promote students' reflection concerning their conceptions about the nature and the organization of chemistry. Third year undergraduate students at the University of São Paulo (USP), being 39 chemistry bachelor's majors and 17 chemistry student-teachers and 30 environmental chemistry students took part in this study. Initially, students were asked to produce a list with the main concepts studied in the different disciplines of the curriculum. Then, students were asked to produce concept maps expressing the relations between these concepts considering the following focal question: *Which are the relations that exist between the main chemical concepts in the undergraduate chemistry curriculum?* In addition to the maps, students also produced a text explaining the rationale that guided the assembly of their maps. The students produced 23 concept maps and texts which are analyzed in the present work. Analysis criteria focused on the more important concepts around which the maps are conceived (the concepts students suggest as "starting points" for building their maps) and how students established links and connections between macro and microscopic concepts. These "starting points" were present in the conceptual maps and the students' texts.

3 Results and Discussion

3.1 The central concept

The combined analysis of the elaborated maps and the texts reveals that, in general students select a “starting point” or a “central concept” around which the organization of the chemical concepts is expressed. The following selected quotes show some of the students´ ideas in this regard:

> “We decided to define as the key concept “chemical reactions” ... From this starting concept ...”
>
> “... the study of this science (chemistry) starts with a small particle, which is the atom.”
>
> “Thus, starting from chemical reaction ...”
>
> “The starting point for the preparation of the concept map is the part of matter commonly studied in chemistry, the atom. From the atom concept, the concepts were related ... “
>
> “This concept map was imagined considering the principle that chemistry originated from chemical reactions, and then the rest was discovered.”
>
> “Considering the chemical reaction as a central concept ...”
>
> “We started by molecular structure, because according to our evaluation, this is the theoretical basis for the whole study of transformation of matter.”

In general, while describing their “central concept” or “starting point” most students chooses a sub (microscopic) perspective, expressed in concepts such as “atom”, “atomic model”, “atomic structure”, “molecule”, “molecular structure”, etc. Figure 1 shows examples of concept maps with different the central concepts.

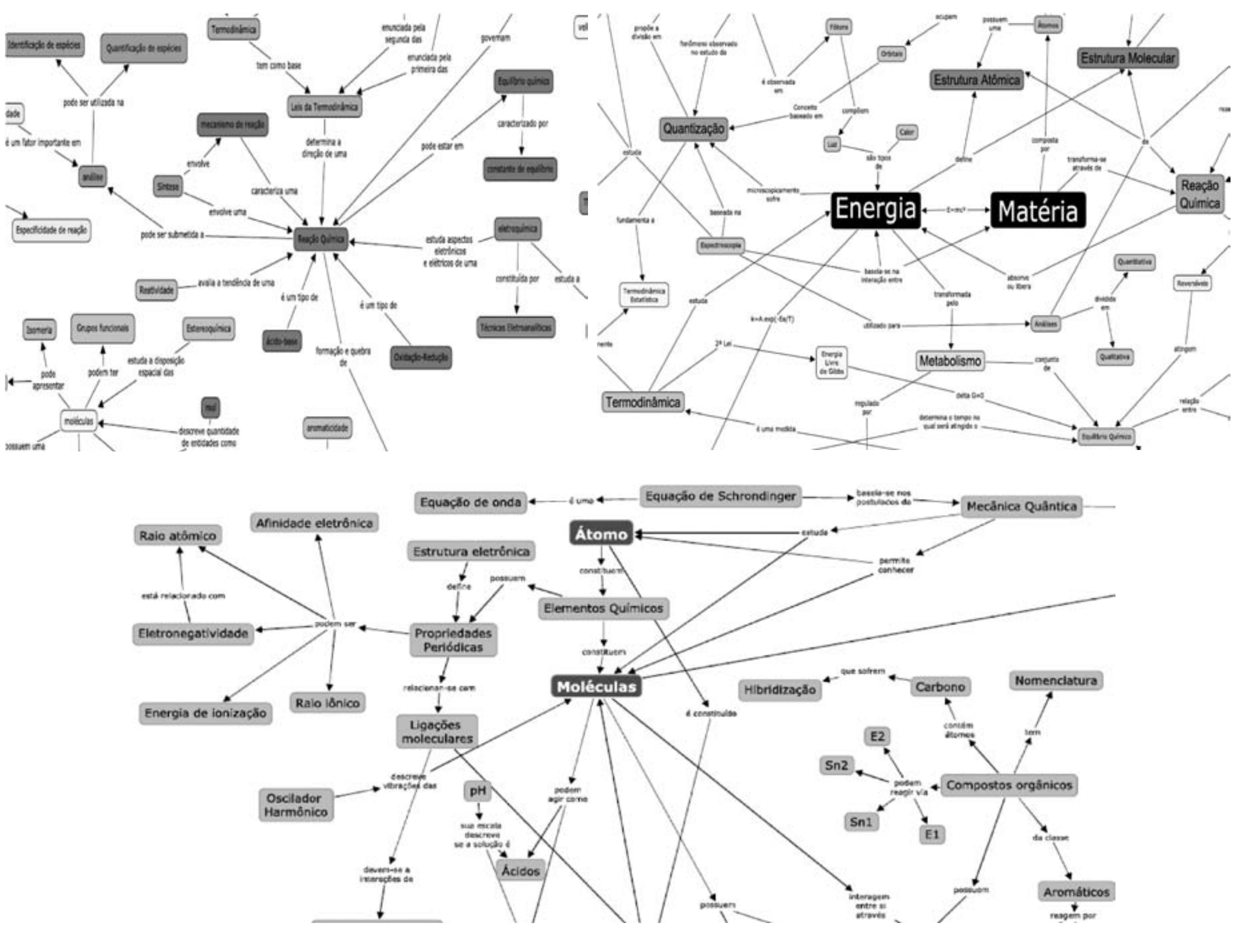


Figure 1. Students´ produced concept maps with the starting points (a) “chemical reaction”, (b) “energy and matter”, and (c) “atom and molecules”.

Analysis of the concept maps produced by the investigated group of students reveals that many maps show as "starting point" the idea of "atom", expressing a vision of chemistry which can be described predominantly as static and structural. Other maps elect the "chemical reaction" as the central concept, expressing a more dynamic vision of chemistry, while considering the centrality of the relationship between chemical substances that are transformed in a given timescale (Schummer, 2002). The number of maps expressing each vision is reported in Table 1.

Prevalent Conception	Concepts	Number of maps
Static Vision	Atom	10
	Molecules	
	Atomic Models	
	Chemical compounds [1]	
	Atomic structure	
	Molecular structure	
	Chemical bond	
	Matter	
Dynamic Vision	Chemical reactions	6
Static and Dynamic Vision	Energy and Matter	2
	Atomic structure and chemical reactions	
	Non-identified	6

Table 1. Central concepts expressed in maps.

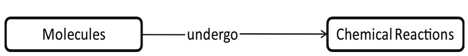
Some students explicitly express the importance of the two levels (macro-and microscopic), as shown in the following quote expressed in student's text:

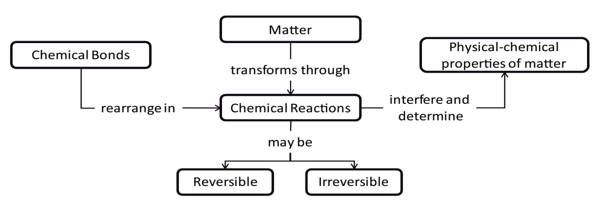
"The construction of conceptual map began with a discussion about chemistry which culminated with the consensus that chemistry is the science of matter, i.e. the study of the properties of materials and the changes matter undergo. Based on this idea, a discussion on the macroscopic and microscopic world begun. During the exposure of ideas we noticed that the understanding of the macroscopic world is based mainly on the understanding of the microscopic world. Thus, the starting point for the preparation of concept map was based on part of commonly studied in chemistry, the atom. From the atom concepts the basic concepts that constitute the main ideas about matter (structure, nucleus and subparticles) were related".

3.2 The "chemical reaction" concept

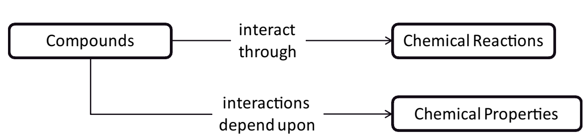
Given the emphasis received by the concept of "chemical reactions" in the concept maps prepared by the students, we also analyzed the ways in which students express this concept in their maps. On one hand, chemical reactions may be described in accordance with macroscopic terms, being related to the production of new chemical substances, or to changes in the properties of substances. On the other hand, chemical reactions can also be seen from the (sub) microscopic point of view, and described as interactions between molecules, rearrangement of atoms, or in terms of breaking and formation of chemical bonds, etc.

With this in mind, we analyzed the concept maps in order to characterize the occurrence of macroscopic and microscopic views about chemical reactions. Microscopic views of chemical reactions are expressed by the following connections:





An example of relation among concepts that emphasize a macroscopic conception is shown in the following connections:



We observed a clear preference of the undergraduate students for the microscopic vision of the concept chemical reactions, which was present in thirteen maps. The macroscopic approach for chemical reactions was emphasized in only four maps. In one of the maps, macroscopic and microscopic views appear with similar emphasis, while in the six remaining maps we have not been able to identify the main approach for the concept of chemical reactions. This data is summarized in Table 2.

Level	Main relations	Number of maps
MICRO	Chemical reactions – reaction between – chemical elements	2
	Chemical reactions – breaking and formation – chemical bonds	3
	Chemical bonds – rearrange in – chemical reactions	2
	Reactions mechanisms – provide information about – reactivity in – chemical reactions	1
	Chemical reactions: - characterized by rate of reaction; - characterized by equilibrium constant; - follow reactions mechanisms; - may follow kinetic and thermodynamics	1
	Chemical reactions – happen when there are changes in – chemical bonds - are used for synthesis	1
	Molecules – interact trough (undergo) – chemical reactions	3
MACRO	Chemical reactions: - are formed by reagents and products; - are the basis of chemical analysis; - are used in industrial processes	1
	Chemical reactions: - use inorganic and organic compounds; - may be: precipitation, redox, complexation, acid-base; - may be biological	1
	Compounds – interact through –chemical reactions Interaction between compounds – depend upon – chemical properties - changes in energy occurs	1
	Chemical reactions: - reach chemical equilibrium; - can be redox, acid-base. Analysis through chemical reactions. Follow the thermodynamic laws.	1
MACRO-MICRO	Molecules – undergo – chemical reactions Quantitative analysis – uses – chemical reactions	1
Non-identified		6

Table 2. Relations involving the concept "chemical reactions".

4 Conclusions

The concepts chosen by undergraduate chemistry students as "central concepts" or "starting points", expressed by conceptual maps and texts, suggest conceptions where there is existence of visions for chemistry that can be described as more "static" or more "dynamic". Some students place structure (atoms and molecules) at the heart of chemical knowledge. Others, however, see the dynamic relationship between substances as the most important aspect of chemistry (the concept of "chemical reactions"). The prevalent tendency observed is structuring chemistry in a manner that would reproduce the structure that this science proposes to matter: at the base the simplest and most elementary entities (atoms) would be, then their combinations (molecules), and then the interactions between these, etc. – in an approach we could describe as ontological (Shummer, 1998). Much less adopted for the structuring of the concepts was phenomenological perspective followed by the more abstract (sub)microscopic concepts.

Acknowledgements

The students who participated on this research and the support from FAPESP, CAPES, CNPq and Pró-reitoria de Pesquisa-USP.

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