CHEMICAL REPRESENTATIONS: BRIDGING SUBMICROSCOPIC AND SYMBOLIC DIMENSIONS OF CHEMICAL KNOWLEDGE IN LIGHT IF PEIRCE'S THEORY OF SIGN

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Abstract

The purpose of this study was to understand the meaning promotion in light of Peirce's theory of sign in a virtual learning environment where students could create and manipulate virtual molecular objects.

Introduction

Representation is an important subject in science education. Thinking chemical representations in macroscopic, submicroscopic symbolic levels, the last one offers more obstacles for understanding in a particulate level, and important properties are better presented by means of computational resources. In this work we present a tool to help high-school students better understand some chemical representations using a virtual learning environment to improve the contact of students with chemical representations in educational activities, and discuss the results in light of Peirce´s theory of sign.

Rationale

Representations are intrinsic elements in chemical knowledge because of its nanoscopic treatment of matter. They present information about macroscopic, submicroscopic and symbolic dimensions of the chemical interpretation of nature. Some representations (e.g. structural formulas) bring both arbitrary and isomorphic information, like element symbols and atomicity, and may be related to logic-mathematical operations or simply point to the aggregation state of a substance. In classroom activities the symbolic dimension of the chemical knowledge may be mistreated only as mathematic formulas, while the submicroscopic dimension is, many times, presented in a two-dimensional way. Thus, important information about the particulate nature of matter is missed, and students are unable to understand those representations as dynamic and interactive.

Despite the importance of correct use of chemical representations, students usually face problems when asked to operate with them in class activities. We then choose to base our study in a theory that explicitly handles representations and the way they reach their meaning. Peirce´s semiotic theory proposes (Peirce 1981) that the relationship between signs and its objects let us classify signs according to their sign-vehicle function due to similarities (icon), existential facts (index) or conventions/laws (symbol). Each dimension of chemical interpretation of nature (macroscopic, submicroscopic and symbolic) has different kinds of representations, and they may vehicle iconic, indexical or symbolic meanings. Submicroscopic dimension of chemistry, which deals with particle interaction and movement, may be better represented now as computational resources are getting more powerful and cheaper. This kind of representation may be classified as iconic when the target is to emphasize the dynamic and interactive nature of particles. Symbolic dimension of chemistry, which deals with representations by letters, number and chemical symbols, are used as a simpler representation and when logical/mathematical operations are necessary. This kind of representation has symbolic (law/convention) meaning when used to represent properties and physical greatnesses.

As some chemical representations have multiple meanings (e.g. structural formulas meaning the amount of atoms and three-dimension positioning), some of these meanings are not clear to students in only-speech classes, and it is necessary to emphasize these meanings in activities where it is possible that students manipulate molecular objects. Concrete molecular objects are useful to these activities, but some dynamic properties, like relative movement of atoms in a molecule, cannot be shown by these means. Computational representations offer the possibility to show students many aspects of the particulate nature of matter. We developed a virtual learning environment where it is possible for students to generate and manipulate three-dimensional molecular objects in a simplified way: using the condensed structural formula of a compound.

Methods

We developed a virtual hypertext learning environment for the student's activities. These activities included creating, visualizing and manipulating representations of both submicroscopic and symbolic levels of chemistry. For submicroscopic level representations we used Jmol Java® applet built-in in hypertext pages which allows the user to manipulate virtual molecular objects. The virtual learning environment included a tool named Construtor, developed by our group, which generates three-dimensional molecular objects from condensed structural formulas of organic compounds (e.g. CH3CH2CH3). This tool was written in C language and runs in a GNU-Linux server, and the students accessed both hypertext pages and Construtor through internet. The virtual learning environment also included a multiple recording system where students´ actions and the screen-in-use were synchronically recorded in digital format. The recording system was built-in in the computer used by the students as softwares running in background and a webcam.

A group of 38 high-school students performed the activities in a computer lab with access to the internet, and they worked in pairs for the proposed activities. A focus group was chosen to be filmed by the multiple recording system during the activities. After 2 sessions of 3 hours each in two different days the group finished the proposed activities and answered a questionnaire. We chose some parts of the recording in which we have observed some change in students' interest, and we have showed these clips individually to them. After watching themselves in a movie (a dual screen with their actions and the screen they were working) we interviewed them and asked if and why their interest had changed at that time. We used these movies to bring to their memories what was exactly happening that time. One of questions from the questionnaire, and part of the interview are analyzed below.

Results

In one of the questions we asked the students to vote about the ease or difficult when using the tool Construtor, where they had to type in a valid condensed structural formula to receive as answer from the server a tree-dimensional molecular object. They were asked to vote in a Likert scale where 1 meant very difficult and 5 meant very easy. Table 1 shows the result.

The categories "normal", "easy" and "very easy" together make 85,3% of the answers, which are the categories with bigger percentage of answers. Despite student´s usual difficulties when dealing with the symbolic dimension of chemical interpretation of nature, the answers show that students didn´t have much difficult to work with these formulas, on the contrary, they found it quite easy to deal with submicroscopic and symbolic representations at once. Peirce´s sign theory helps understand why students face problems to understand particulate properties from letter-and-number representations, but they do not face much problem when dynamic molecular objects are put together. According to his theory, iconic representations mean by similarity (visual or in properties) to its objects (target meaning). It is easier to students to understand stereo constraints in a molecule by observing and manipulating a molecular object with appearance of balls and sticks than drawing letters and number to them. Balls and sticks together forming a molecular model look more familiar to them then numbers and letters linked by traces.

Table 1. Student´s percentage of answers when asked about difficulty or facility to using the tool Construtor, in which they faced both representations of submicroscopic and symbolic chemical dimensions.

%	Likert scale
2.9	1 – Very difficult
11.8	2 – Difficult
23.5	3 – Normal
47.1	4 – Easy
14.7	5 – Very easy

When interviewing one of the students, after showing him a video about his activities in the lab, we asked him why he got more interested when he first saw that the tool Constructor would return him a tree-dimensional molecular object, after typing a formula. Actually the video showed him and his partner laughing and clapping after the result. We quote his answer below:

"It is funny, ´cause I look at this table, and <u>I can´t imagine all that little balls</u> (ball and stick models, both concrete and virtual) in this table. This table is made from a lot of these little balls, these molecules. You look at it and <u>you can´t see atoms in stuffs</u>, but then you see that stuffs… <u>I know that stuffs are made from atoms</u>, but I can´t see atoms, so when guys can see it´s cool, it´s interesting".

When students have no contact with representations of the submicroscopic dimension of chemistry, it is possible for them "to know" that things are made from atoms, and also "know" dynamic properties of molecules. But it is quite complicated to them "to imagine" these properties because there is nothing really alike in macroscopic world available in everyday life, and also because no one might 'see' atoms. Nowadays it is possible to show them these properties taking advantage of computational resources and the iconicity it is able to mimic.

Conclusions and Implications

Maybe one of the best situation to teach chemistry would be students writing and manipulating three-dimensional representations full time. As it is not possible because of the complexity of these representations, there is a symbolic dimension in chemistry to represent also the submicroscopic aspects. But these representations do not help students to imagine or understand important particle properties, and some might even believe that chemical symbols have just logical-mathematical purposes.

Table 1 shows that students do not found difficult to deal with symbolic and submicroscopic representations. As they generated these representations by typing in the corresponding formula and could easily manipulate the molecular objects, three-dimensionality and dynamic properties became more concrete to them, instead of just trying to imagine the corresponding submicroscopic world. Also the interview suggests that seeing and manipulating molecular objects along with the symbolic representations make it possible to students to bridge submicroscopic chemical world and its symbolic representations. It may be a way to broad students´ conventional meaning of bi-dimensional representations, as they will face them more frequently than any other.

Reference

Peirce, C. S. (1981). *Writings of Charles S. Peirce: A Chronological Edition* (Indianapolis, IN: Indiana University Press).

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