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CONCEPT MAPS AS TOOLS FOR ASSESSING THE MERGE OF DISCIPLINARY KNOWLEDGE DURING CHEMISTRY CLASSES AT HIGH SCHOOL

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Abstract. Concept maps (Cmaps) were used as tools for checking the conceptual changes caused by a didactical activity implemented in a Brazilian high school. Its pedagogical aim was to break down the boundaries, which segregate the scientific knowledge into isolated disciplines. The students were intentionally provoked to merge concepts from Chemistry and Biology, in order to better understand and explain the biological consequences of the isomerism phenomenon. The Cmaps produced by the students before and after the proposed activities confirmed the appearance of relationships among chemical and biological concepts, which were be evaluated from the quantitative and qualitative points of view. Thus, this work concluded the Cmaps can be used to measure the students' progress toward the interdisciplinarity (ID), and to help the teacher to devise future classroom activities to reinforce and to expand ID relationships.

1 Introduction

The recent explosion of the scientific knowledge and the new paradigms of the post-industrial society have imposed new challenges to education (Hobsbawm, 1996; Morin, 2001). The role of scholar education, the revision of pedagogical strategies adopted by teachers, and the formation of conscious and emancipated citizens are hot subjects to respond the new demands posed by the knowledge societies of the 21st century (Unesco, 2005). The relevance of these educational issues is attested by United Nations, which declared the years between 2005 and 2014 as the 'Decade of Education for Sustainable Development' (Pérez et al., 2005). Among all issues brought to this debate, the pursuit of interdisciplinarity (ID) can be highlighted as a key-point to change the classroom dynamics, which is chiefly based on teachers' expositions. Besides being a teacher-centered activity, the lectures frequently involve disciplinary topics, impairing the students' perception about the ID nature of the knowledge (Klein, 1996; Weingart & Stehr, 2000). This aspect becomes even more relevant when we analyze how science has been taught at high schools, breaking down the scientific knowledge into isolated disciplines. The imaginary boundaries, which segregate Biology, Chemistry, Geology, and Physics, are emphasized and the students cannot make meaningful associations among their concepts (Donnelly, 2005). Therefore, the students do not perceive the beauty of natural sciences as a whole, and they are not able to make mindful decisions about the complex scientific issues posed to our society (Unesco, 2005).

The planning of ID activities and their implementation at the classroom are decisive for encouraging the merge of scientific disciplinary knowledge. The teacher must provoke the students to think beyond these didactical boundaries, to stimulate changes in their cognitive networks toward the establishment of relationships among concepts from different knowledge domains (Galagovsky, 1993). This ID approach can conduct to an improvement of the science education, increasing the meaning of its contents, and stressing the connections between scholar and real-life knowledge. Concept maps (Cmaps) are critical evaluation tools in this context (Novak, 1998), to verify the changes in the students' cognitive networks after developing the planned ID activities. They can show if the students made up relations between concepts from different scientific disciplines, exploring both quantitative (*e.g.*, how many ID connections were established?) and qualitative (*e.g.*, how deep and correct are the ID connections?) aspects (Wanderse, 1990). Moreover, Cmaps can also help the teacher to devise future classroom activities to reinforce and to expand the established ID relationships. Thus, the goal of this work is to use Cmaps to evaluate the effectiveness of a planned ID intervention, from the assessment of the changes at the students' cognitive networks.

2 Cmaps for searching ID relationships

2.1 High school, students, and Chemistry classes: a brief description of the local context

The present work was developed at a high school located at the São Paulo metropolitan area (Colégio Objetivo, Suzano, SP, Brazil). Thirty students at the 11th grade were invited to attend 100-min extra-classes once a week (in the afternoon), after their 6 regular classes (in the morning, 50-min each), to learn how to build up Cmaps, and to discuss some biological consequences of the isomerism phenomenon. During the regular classes involving Organic Chemistry, the teacher presented lectures about molecular structure and spatial isomerism (geometric and optical). The afternoon extra-classes provided Biochemistry discussions about the effects of isomerism phenomenon at the living organisms (Atkins, 2003), as shown in Table 1. Firstly, the geometric isomers of the retinal molecule were considered, and their roles during the photochemical events in vision were explored. Secondly, the enantiomers of thalidomide were discussed as a sedative drug (one isomer), and a teratogenic agent (the other isomer).

2.2 *Introducing Cmaps to these high school students*

Considering the students involved in this project did not know what Cmaps are, introductory activities were devised (Table 1) to supply guidelines for building up hand-made and electronic Cmaps (CmapTools, v. 3.10, IHMC, Pensacola, FL, USA). They always worked in groups of up to 5 students, to encourage the collaborative learning among them. After concluding the didactical activities, the Cmaps obtained at the weeks #3 and #5 were used for the research purposes. The Cmaps produced after week #3 present the students' cognitive networks about isomerism, from the disciplinary (chemical) point of view. They reflect the knowledge developed during the regular classes about Organic Chemistry, when teacher's lectures prevailed. On the other hand, the Cmaps presented after week #5 are the product of the knowledge merging from both, regular Chemistry and Biochemistry extra-classes. Therefore, the comparison between week #3 and week #5 Cmaps may bring evidences of the students' cognitive changes, taken into account the connections among concepts from isomerism and its consequences for living organisms.

Table 1: Didactical activities developed at Colégio Objetivo, exploring the teacher's disciplinary approach during the regular Chemistry classes, and the ID discussions about Biochemistry during the extra-classes.

Week	**Topic**		**Concept map activities**
	Regular classes	**Extra-classes**	**Homework**
#1	Geometric isomerism	Guidelines to make up Cmaps	HM Cmap[a] about Organic Chemistry
#2	Optical isomerism 1	CmapTools presentation	E-Cmap[b] from the week-1 HM Cmap[a]
#3	Optical isomerism 2	Retinal discussion	E-Cmap[b] about isomerism
#4	Chemical reaction 1	Thalidomide discussion	-
#5	Chemical reaction 2	Biology and isomerism	E-Cmap[b] about isomerism and Biology

[a]HM Cmap: Hand-made concept map; [b]E-Cmap: Electronic concept map made up by using CmapTools.

3 Results and discussion

The comparison of the Cmaps produced at week #3 and week #5 took into account quantitative and qualitative aspects. The former are presented in Table 2, and some parameters are proposed for this evaluation. The B/C ratios between Biochemistry (B) and Chemistry (C) concepts reveal the disciplinary nature of the week #3 Cmaps, considering the absence of biochemical concepts. The B/C ratios are zero for them, emphasizing the scientific knowledge segregation at isolated disciplines during the secondary education. These Cmaps about isomerism use only concepts provided during the regular classes about Organic Chemistry, making no relationships with knowledge from other scientific area (Figure 1a). Conversely, the week #5 Cmaps showed the merge of chemical and biochemical concepts: the B/C ratios (Table 2) indicate the presence of new knowledge, acquired during the extra-class discussions about biology and isomerism. Moreover, the week #5 Cmaps presented 3-times more concepts than the week #3 Cmaps, further exploring the isomerism from the biochemical point of view (Figure 1b).

Table 2: Quantitative parameters estimated from the Cmaps produced by the students before (week #3) and after (week #5) the planned ID activities.

Week	**Group**	**# of concepts at the Cmaps**			**B/C ratio**	**# of concepts in the text (Tx)**	**B/Tx ratio**
		Total	**Biochemistry (B)**	**Chemistry (C)**			
#3[a]	A	12	0	12	0	-	-
#3	B	14	0	14	0	-	-
#5[b]	A	38	9	29	0.31	21	0.43
#5	B	40	12	28	0.43	21	0.57

[a]Cmap presented in Fig. 1a; [b]Cmap presented in Fig. 1b.

Before asking the students to prepare the week #5 Cmaps, they read a 2-paragraph text summarizing the extra-class discussions about vision (role of retinal molecule) and drugs (biological effects of thalidomide enantiomers). It was used for activating the students' cognitive networks, asking them to select some words offered in the text with the aim of making up the Cmap. The effectiveness of this procedure can be estimated by calculating the B/Tx ratios between Biochemistry concepts that appear in the Cmaps (B), and the total number of biochemical concepts offered in the text (Tx). The found values (Table 2) confirmed the students incorporated new concepts to the week #5 Cmaps, making relationships between the chemical concepts involving isomerism and the biological consequences discussed during the extra-classes. Beyond enriching the week #3 Cmaps, they established ID connections between two different knowledge domains (Chemistry and Biology), and started to use Biochemistry to better understand and explain the selected scientific issues.

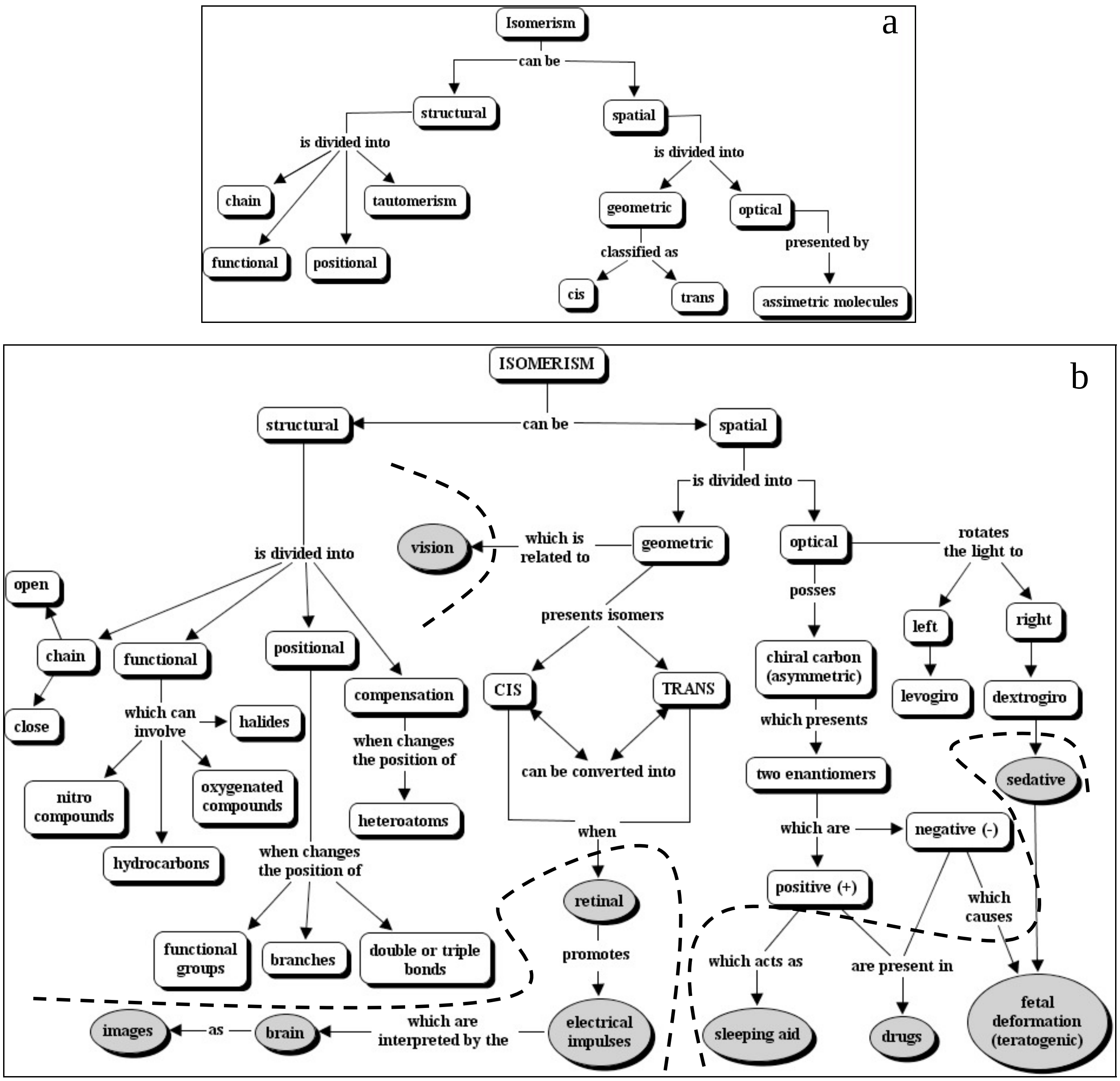

Figure 1. Cmaps about isomerism produced by the students using CmapTools. (a) Cmap produced at week #3, before the extra-class ID discussions. (b) Cmap produced at week #5, after the extra-class ID discussions. The broken lines represent the boundaries between the disciplinary concepts from Chemistry and Biology (highlighted in circle-shadowed boxes).

The comparison between the week #3 and week #5 Cmaps shown at Figure 1 emphasizes the changes in the students' knowledge networks after carrying out the planned ID activities. It also allows a qualitative evaluation, which complements the quantitative analysis presented at Table 2. The structure of week #3 Cmap (Figure 1a) presents only chemical concepts related to isomerism, and this knowledge network reflects the disciplinary discussions made by the teacher during her lectures. This background knowledge is repeated in the week #5 Cmap, and the students used it as starting point to make up connections with the biological concepts (Figure 1b). Therefore, the chemical concepts provided during the regular classes still plays a central role for understanding isomerism, but the ID approach offered in the extra-class discussions was incorporated into the students' knowledge networks.

It should be stressed that Cmaps are not definitive and they change when new relationships are established in the individual's conceptual networks (Moreira, 2000). In the context of this work, Cmaps confirmed their potential to verify the merge of disciplinary knowledge by mediating the meaning negotiation of concepts from different scientific domains. Therefore, mechanical learning of the fragmented science contents was avoided, prevailing a meaningful learning from the ID point of view.

4 Summary

The concept maps (Cmaps) are valuable tools for assessing the effectiveness of the conceptual changes provoked by didactical activities done at the classroom. This work shows how the Cmaps can be used to evaluate the students' progress toward the interdisciplinarity (ID), which is a critical condition to improve the science education of the 21st century. Beyond checking the students' performance, the Cmaps can also support the teacher's action in the classroom. They provided insightful information to devise future activities to reinforce the ID connections made by the students, and to further extend the ID discussions as well.

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