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Conceptual Profiles: Theoretical-methodological Grounds and Empirical Studies

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Abstract

In this paper, we briefly address the theoretical and methodological grounds of the conceptual profile theory and discuss two empirical studies aiming at constructing conceptual profile models and using them to analyze classroom discourse in different sciences, chemistry (entropy and spontaneity) and biology (adaptation). The basic idea is to illustrate how these models were built, considering differences and similarities between the methods used for this purpose. Conceptual profiles are *models* of different modes of seeing and conceptualizing the world used by individuals to signify their experience. They are built for a given concept and are constituted by several zones, each representing a particular mode of thinking about that concept, related to a particular way of speaking. Each zone is individuated by ontological, epistemological, and axiological commitments underlying discourse. We will show how different concepts, situated in sciences with different levels of conceptual polysemy, demand different methodologies to deal with the variation found in meaning making in the sociocultural, ontogenetic, and microgenetic domains.

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Keywords: conceptual profiles; classroom discourse; heterogeneity of verbal thinking; entropy; adaptation

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1. Introduction

The idea of a conceptual profile, namely, that people can exhibit different ways of seeing and representing the world, used in different contexts, was proposed in the 1990s (Mortimer, 1995), initially inspired by Bachelard's epistemological profile. It was framed as an alternative to the claim in theories and models of conceptual change (such as Posner and colleagues', 1982) that science learning involved breaking away from everyday knowledge, students' previous concepts, and worldview tenets. The underlying idea is that verbal thinking is heterogeneous and, thus, word meanings are often polysemous, both in science and in everyday language. In subsequent developments, conceptual profiles were integrated into a theoretical framework treating science learning as learning the social language of school science through classroom discursive interactions, analyzed from a sociocultural perspective (Mortimer & Scott, 2003). In this framework, the following theories are integrated into a synthesis made coherent by several shared assumptions, characteristic of sociocultural approaches: conceptual profiles, as tools for analyzing modes of thinking; the theory of language of the Bakhtin circle, as a basis for analyzing ways of speaking; Vygotsky's theory of the development of higher mental functions, as a basis for investigating learning; Mortimer and Scott's framework for research into classroom communicative approaches.

Conceptual profiles are models of different modes of seeing and conceptualizing the world used by individuals to signify their experience (Mortimer & El-Hani, 2014). In any classroom there is inevitable heterogeneity in modes of thinking and talking. In order to build a theory about teaching and learning, which allows us to intervene in classroom dynamics in an informed manner, we need to model this heterogeneity of speech and thought.

In conceptual profile theory the problem of generating new meanings in science teaching is framed in terms of the interplay between modes of thinking and ways of speaking, considering the coexistence in the individual of two or more meanings for the same word or concept, accessed in the appropriate contexts. This coexistence is possible even within scientific concepts, in which the dissonance between classical and modern views of the same phenomena is a norm, not an exception.

Conceptual profile models are built for a given concept and are constituted by several zones, each representing a particular mode of thinking about that concept, related to a particular way of speaking. Each zone is individuated by ontological, epistemological, and axiological commitments underlying discourse. The construction of profile models are based on several sources: historical and philosophical studies, literature on alternative conceptions, textbook analyses, and treatment of primary data on students' views, gathered by both questionnaires and interviews, as well as on discursive interactions in science classrooms. By using these sources, we investigate three Vygotsky's genetic domains – microgenetic, ontogenetic, and sociocultural.

Each individual has her own conceptual profile, but it is only the relative importance (or 'weight') of the zones that varies from person to person, while the zones or modes of thinking themselves are shared by individuals in a culture, as maintained by sociocultural approaches to human action. Those differences in relative importance depend on the individual's experience, which offers more or less opportunities for applying each zone in its appropriate contexts. Science learning has, thus, the key role of increasing the importance of the scientific zones in students' thinking about a concept. Conceptual learning is conceived in the theory as two interwoven processes: the construction of new modes of thinking and ways of speaking, in science education specifically the scientific zones (a cognitive process); and the dialogue between new and old zones, with a focus on the need that students become aware of the very diversity of modes of thinking and the demarcation between their pragmatic value in distinct contexts (a metacognitive process).

We established a research program on how people learn scientific concepts and how these concepts can be taught through dialoguing with the heterogeneity of language, meaning and verbal thinking. The basic tasks in this research program are: 1) determining the zones that constitute the conceptual profile for a number of key scientific concepts, which are both polysemous and play a central role in science education; 2) Investigating how these zones appear in different people as a way of characterizing individual conceptual profiles; 3) Investigating the interplay between different modes of thinking and ways of speaking in real science classrooms. We will consider here two studies dealing with tasks 1 and 3 above. In the research program on conceptual profiles, we initially chose three basic concepts – matter, energy, and life – and filled out the first task of the program for all these concepts. We unfolded them into other (subordinate) concepts in order to make their study feasible. In the case of energy, we studied the concepts of heat, entropy and spontaneity of physical and chemical processes; and for life, the concepts of life/living beings and evolutionary adaptation. Here we will focus on the concepts of entropy and spontaneity of physical and chemical processes, on the one hand, and adaptation, on the other hand, because they will allow us to illustrate differences in the methodology used to investigate conceptual profiles related to different domains of science. For reasons of space, we will not discuss how these profiles were put to use in analyzing classroom discursive interactions.

2. How to build and use conceptual profile models

The need of working with different genetic domains to build profile models follows from the theoretical claim that the zones of a profile are individuated by ontological, epistemological and axiological commitments that stabilize ways of thinking and speaking about concepts. To identify these commitments, it is necessary to put into dialogue secondary literature about the history of science, epistemological literature, the literature about alternative conceptions, and primary data obtained from questionnaires, interviews, textbook analysis, and analysis of episodes of discursive interaction in the classroom. The goal is not to find parallels between domains, or to endorse the idea that ontogenesis recapitulates the sociocultural historical genesis, but rather to investigate a broad range of meanings attributed to a concept by considering data from all these genetic domains, and, thus, a diversity of meaning making contexts. The idea is to build conceptual profiles that are more powerful and fertile models of the heterogeneity of ways of thinking and speaking available in a society for use in a range of contexts or domains of experience.

An important methodological principle for building conceptual profiles is that one should strive to put the different genetic domains in dialogue. One should allow a mutual influence between the sources used, in coherence with the idea of working with different genetic domains, instead of reducing the process to a unidirectional influence from one information source over the others.

The profile models are applied to the discursive analysis of teaching episodes produced in school contexts as a guide to the semantic analysis of discourse, integrated to the analytical structure developed by Mortimer and Scott (2003) to describe the way teachers and students interact in meaning making in the science classroom.

3. Building a conceptual profile model of entropy and spontaneity

To construct a conceptual profile model of entropy and spontaneity, we drew upon contributions from the history of science, science education literature on alternative conceptions, and science classroom investigations, aiming at considering a broad and significant range of ideas related to different genetic domains.

Research on how students understand chemical reactions usually describes their conceptions about what is a chemical reaction, how fast it occurs, whether they absorb or release energy, among other issues. However, another important question related to this topic does not receive the same attention: Why does a chemical reaction occur? Or, in a more focused way, under what conditions may a chemical reaction happen or not happen? The answer to this question must address the consequences of the second law of thermodynamics for the study of physical and chemical transformations, which implies, in turn, an understanding of the concepts of entropy and spontaneity. This will foster a deeper understanding of the physical and chemical transformations in the context of chemistry teaching and learning.

Although strongly rooted in everyday experience, spontaneity is often not explicitly addressed as a concept in higher education physics and chemistry textbooks. However, the word "spontaneous" is often used by these same textbooks to characterize processes that occur under certain conditions. Our choice for treating spontaneity as a concept is justified in considering that this idea can work as a link between everyday conceptions that students have about changes and more formal concepts of entropy and free energy.

Based on the historical literature and literature on alternative conceptions, a conceptual profile model containing three zones was proposed: the perceptive/intuitive, the empirical, and the rationalist zone. As the naming of the zones shows, Bachelard's (1940) epistemological profile zones was an important source of inspiration to build the model.

The *perceptive/intuitive* zone concerns a mode of thinking that involves immediate perceptions, sensations and/or intuitions, and arises from empirical experience and personal interpretations. It does not concern the concept of entropy, since this would involve a more scientifically elaborated understanding of the phenomena at stake. Therefore, spontaneity is the focus of this zone, related to ideas about phenomena that occur naturally, without outside interference. It is important to emphasize that conceptions supported by immediate impressions, sensations and intuitions prompt subjective understandings of phenomena (Bachelard, 1938). As Bachelard argues, these ideas are not subjected to rational criticism, constituting an ingenuous realism, and once they are formed at an unconscious level, they are difficult to approach at an intellectual level.

In the literature on alternative conceptions, we find ideas about chemical reactions that appeal to a notion of spontaneity. For example, Andersson (1986) found that 10% of the students in his study considered that the appearance of a thin and dark crust on copper water taps was expected, being explained as something that just occurs. Mortimer and Miranda (1995) drew attention to students' explanations of iron rusting as a natural tendency of this material. From such research findings, we can see that some students express intuitive ideas, based on their immediate perceptions of phenomena when dealing with chemical reactions or, generally speaking, changes in matter. In this sense, the spontaneity of physical and chemical processes is related just to processes that seem to occur naturally.

In the classroom investigated in this study, ideas related to the perceptive/intuitive zone emerged mainly in the initial discussions. For example, before introducing the entropy concept, the teacher asked the students about what they understood by spontaneous processes. Some students said that spontaneous processes are those that occur without an external force or catalysis. They mentioned examples such as iron rusting, evaporation, and water condensation. This suggests that, for the students, spontaneous processes occur naturally, without any explicit action to drive them and without any imposed or needed conditions. This is close to the commonsensical idea that any situation occurring naturally is a spontaneous one. Nevertheless, when the entropy concept is used to explain the occurrence of phenomena in terms of energy distribution (Atkins, 1994), it supports an understanding of spontaneous processes that goes beyond those occurring naturally (without external interference) and/or with macroscopic evidence.

When students use in the classroom the mode of thinking captured in the perceptive/intuitive zone, they are rarely asked to reflect on the differences between everyday and scientific views about phenomena. However, in the school context it is important for subsequent learning that ideas from the perceptive/intuitive zone are discussed and compared to other ways of thinking.

In the *empirical* zone, ideas about spontaneity are related to the prevailing conditions for the occurrence of processes. Some conditions might relate to specific values of the physical properties of a system or substance (temperature, pressure, etc.), and, also, to ideas about the disorder of the system and a specific mathematical formalism leading to decision making on familiar processes as if they were spontaneous or not. In this zone, it is common that algorithms and mathematical formulae are applied in analyzing physical and chemical processes without a complete understanding of the conceptual relationships at stake. In general, students use the expression of entropy or the equation for free energy - a more complex concept that relates entropy, enthalpy, and temperature -, but often they do not clearly understand what these expressions represent. This is an important limitation in their thinking, since empiricism is not far from theories, as Bachelard (1949/1977) discusses, because theories are implied in experience. The use of mathematical formalism without a complete understanding about the theories involved distinguishes the empirical from the rationalist zone.

In this zone, however, students are taken beyond immediate perception of phenomena through the discussion of the physical conditions or values (for entropy, enthalpy, temperature, free energy) under which the process occurs spontaneously or not. Although values for the change of entropy and/or free energy cannot be obtained from direct measurement, teachers often encourage students to use these values as an empirical measure. This provides a first empirical approach to the concept of entropy, which could help students in understanding it (Atkins, 1994). Students tend primarily to associate entropy with the idea of disorder or clutter (Lowe, 1988). The increase of entropy is related to the increase in disorder and is taken as the indicator of the occurrence of spontaneous processes. Those phenomena that occur spontaneously are seen as promoting disorder, which means higher entropy (Lowe, 1988).

In the classroom we investigated, the students considered the analysis of water vaporization using values of temperature and pressure to define the physical conditions for which this process should be spontaneous (at 100°C and 1atm). Although the students' ideas resulted from the analysis of a particular chemical or physical process, classroom discussions aimed at reaching explanations or generalizations. Despite the familiarity of the process for the students, they got confused in reaching the physical conditions in which it could be considered spontaneous from a sci/entific perspective, probably because 100°C is not the temperature of the natural environment. When students considered the conditions to consider vaporization of water as a spontaneous process, they were faced with a difference between the commonsensical idea about naturally occurring phenomena and the scientific view on spontaneity. In this case, empirical evidence played an important role in promoting their understanding beyond the mathematical formalism involving entropy change. Given the conflict between empirical evidence and mathematical formalism, the empirical zone can be characterized by transitions between perceptive and rational ideas, and, thus, play an important part in the teaching and learning context.

The *rationalist* zone amounts to a mode of thinking that considers entropy and the spontaneity of physical and chemical processes by drawing on the distribution of energy in an atomic-molecular level. In this manner, these concepts are understood in a deeper manner, with students addressing entropy and spontaneity in relation to microscopic models of energy distribution of molecules, and, thus, conceiving entropy as part of a more complex notion related to free energy. The relationship between entropy, enthalpy and temperature, presented in the expression for free energy, can be discussed as a path to determine a set of conditions which enable us to know the direction of a spontaneous physical or chemical process. In this case, spontaneity is related to the conditions promoting transformations in a specific direction. The occurrence of a spontaneous process is related to an increase in the number of ways of distribution of energy in a system at a molecular level and can also be related to a greater spatial randomness (Lowe, 1988). This concept of spontaneity is very different from the idea of natural occurrence of processes.

The discussion about the distribution of energy at the molecular level is a step towards the rationalization of the entropy concept, but it is not an easy task to address in classrooms (Bickford, 1982; Lowe, 1988). For these authors, the introduction of atomic and molecular entities in classroom discussion could lead students to a rational way of thinking about spontaneity. Sometimes, the idea of energy becoming distributed across molecules was reported by students in terms of "spreading as evenly as possible", and not in terms of the probable states of a system. This idea sounds like an approximation to the meaning of disorder, as outlined earlier.

In our classroom study, theoretical ideas about entropy and spontaneity were discussed to reach explanations about empirical situations and to understand generalizations presented by the textbook. The discussion about the distribution of energy was addressed in terms of the probable arrangement of molecules in a system, using a diagram proposed by the textbook. From figures based on colored balls, the students tried to advance claims related to an atomic-molecular level, firstly seeking to address what the balls represented. The students seemed to go beyond their perceptions and/or subjective impressions towards an interpretation of empirical data, starting a process of developing their own hypotheses. Nevertheless, we realized that they did not reach a complete understanding of the theoretical models for entropy. This is a difficult achievement even for higher education students and maybe for teachers as well. The rationalist zone represents a desirable level of understanding to be reached by the students in the teaching and learning process in the science classroom, despite the difficulties faced by them.

4. Building and using a conceptual profile model of adaptation

To understand the genesis of the concept of adaptation in the socio-cultural, ontogenetic, and microgenetic domains, we used secondary sources about the history of biology and epistemological treatments of the adaptation concept; literature on students' alternative conceptions about the concepts of adaptation and natural selection; empirical data collected through interviews and questionnaires with high school and higher education biology students; and data from videorecording of discursive interactions in the classroom. From the dialogue between these sources of information, we produced a tool that we called an "epistemological matrix" about the concept of adaptation, amounting to a synoptic table where epistemological themes from which one can signify the concept of adaptation are organized, and, for each of them, a set of ontological and epistemological commitments was identified, structuring the interpretations of this concept. In this epistemological matrix we identified six epistemological themes from which evolutionary adaptation can be signified: ontology; causal factor: causal mechanism; nature of adaptation as a solution to problems challenging the survival and successful reproduction of the organism; necessary and sufficient conditions for a trait being an adaptation; role of the concept in the explanation of organic form (for more details, see Sepulveda et al., 2013, 2014). The zones of the profile model were established through a combination of different ontological and epistemological commitments related to each epistemological theme shown in this matrix. To choose these commitments we considered the educational context in which we intended to use the conceptual profile model as a tool to analyze the semantic dimension of classroom discourse, namely, the high school level. After all, the relative importance of each theme included in the matrix vary among educational contexts. Taking into account that in high school the focus lies on teaching and learning about the Darwinist conception of the evolutionary process as a way of explaining the overall form of living beings, and, in particular, their adaptations, we focused our attention on the themes of ontology, causal factor, and causal mechanism, constructing a profile model containing four zones: intra-organic functionalism; providential adjustment; transformational perspective; variational perspective.

Intra-organic Functionalism is a zone including interpretations of adaptive traits in which they are not conceived as phenomena requiring evolutionary explanations. Another way of explaining the existence of adaptive traits without searching for evolutionary causes consists in emphasizing the description of the functional attributes of these traits, focusing only on their role in the maintenance of the organic system itself. In our empirical data, this view frequently emerged when students were asked during interviews or classes to interpret a scenario concerning the morphological diversification of the mammalian jaw. Often, they explained the variation in the morphology and number of teeth composing the dental arch of different groups of mammals by the function played by each tooth in the operation of the whole dental arch during the chewing process. The role of these morphological structures in the functioning of the system to which they belong is described in these terms, with no explanation of their origin through this functional attribution. Functionalist views of this kind differ from the Darwinist perspective, since they do not address the biological role (Bock & Wahlert, 1989) played by the structure through a connection to its contribution to the differential survival and reproduction of its bearers. Three epistemological commitments seem to be involved in the genesis and structuring of this way of thinking: adaptation is seen as self-evident and/or self-explanatory phenomenon; an emphasis on proximate causes; and an intra-organic teleology, from which the existence of structures is explained in virtue of their causal role in preserving the intra-organic harmony (Caponi, 2002). This way of thinking creates a difficulty to the construction of the Darwinist interpretation of adaptation in the classroom, since the Darwinist problem of adaptation, focused on the relation between the complexity of the organic form and the struggle for survival, is not formulated from its perspective.

In *Providential Adjustment*, adaptation is conceived, in ontological terms, as a state of being or property of an organism being adjusted to its conditions of living. Epistemologically, this adjustment is explained by appealing to either some principle of the economy of nature or a teleological perspective about the organization of living forms. Adaptation is explained as a phenomenon resulting from a necessary harmony between the structural organization of an organism and its conditions of living. An essentialist view about the identity of species is also associated with this way of thinking about adaptation. But it also embodies an aspect of the organic world stressed by Darwinist views: the functional correlation between organic structure and living conditions. Accordingly, it may be used in the classroom as a manner of turning the students' attention to this aspect, as a seed for conceptual evolution towards the goal of understanding the variational perspective. However, there are also difficulties related to this way of thinking, regarding students' learning about Darwinist explanations: the functional correlation is explained in finalistic or teleological terms, as the result of the fulfilment of a predetermined goal; it is not easy to build the notion of an struggle for existence and a historical perspective when the students assume a preordained world in which everything is arranged in a manner that leads to the best possible state of things.

The main difference between the *Transformational Perspective* and the previous zone is the introduction of a historical, evolutionary perspective to explain the diversity of organic forms. Adaptation is interpreted as a process of transformation of the essence of the species towards an optimum (teleological) state of adjustment to the environmental conditions. This process occurs through simultaneous changes in each and all of the individual members of a species. Evolutionary (phylogenetic) changes are conceived as the result of accumulated ontogenetic changes. Another characteristic of this way of thinking is the idea that the transformation suffered by organisms has a definite direction, all the members of the species undergoing changes oriented in the same direction and following a common sequence of steps. These transformational views are evolutionary approaches, but still retain a core of essentialist thinking. Variation is not a central feature in this way of thinking. Thus, an essentialist and typological view about the species is a commitment shared by this zone and the previous one. Essentialist thinking, the focus on the individual organism, and the emphasis on proximate causes are ontological and epistemological commitments of this zone that create difficulties to the development of a variational perspective. However, we can see a consequential change in the ontology of adaptation if we compare transformational perspectives and providential adjustment views: adaptation is no longer conceived as a state of being or property of a morphological structure or organism; rather, adaptations are described as processes of evolutionary change. This change in the ontological categorization of adaptations is a seed for the development of a variational way of thinking.

In the *Variational Perspective*, we find interpretations of adaptations as traits resulting from natural selection, which leads to the spread and fixation of variants in a population under a given selective regime. The demarcation between these latter two zones is grounded on Lewontin's distinction between variational and transformational explanations of evolutionary change (e.g., Levins & Lewontin, 1985). In variational accounts, evolution is conceived as the result of changes in the proportion of variant organisms in a population. While the population changes from generation to generation, inheritance plays the role of keeping organismic traits invariant to a significant extent. This tension between change at the population level and invariance at the organismic level plays a central role in variational explanations. We need to consider, also, how to differentiate functional explanations in intra-organic functionalist and variational accounts. In the former, what is at issue is how a structure or behavior functions or operates in order to maintain the organic system to which it belongs. In the case of the variational, selective explanation, we explain how the structure or behavior plays a given function in a better or more efficient way than feasible alternatives, or under which selective pressures the structure or behavior can result in organic forms that are better than equally viable alternatives from the morphological, physiological or phylogenetic point of view (Caponi, 2002). We find in the variational zone, many ontological and epistemological commitments typical of the Darwinist explanations: population thinking; the idea that organic structures have a central role in the struggle of organisms to survive and to successfully reproduce in constantly changing ecological settings; and a historical perspective on organic forms.

5. Different concepts demand different methodologies to build conceptual profile models

The major difference between these two studies using conceptual profiles lies in the process of constructing these models. Different concepts demand different methodologies to deal with the variation found in meaning making in the sociocultural, ontogenetic, and microgenetic domains, because they are embedded in sciences with different levels of conceptual polysemy. In the study on entropy and spontaneity Bachelard's epistemological profile zones were adequate to guide model construction and there was no need to tailor the model to a particular educational level. In the study on adaptation, Bachelard's approach was recognized as insufficient from the very beginning of the study, since it would not lead to an adequate construction of a conceptual profile model that could deal with the large diversity of different problems related to adaptation. Therefore, before building the model, we built an epistemological matrix organizing meaning making about problems so different as what is the ontological nature of adaptation and what are the causal mechanisms driving adaptive evolution. From this epistemological matrix, we chose a specific educational level to address, namely, high school, and then analyzed the matrix to verify what content would be adequate for students at that level, focusing on that content to build the profile model. In our view, the key difference between concepts that can lead to different approaches to build profile models concerns the degree of polysemy, which varies between disciplines, but also between educational levels.

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