Chapter 8
A Conceptual Profile of Entropy and Spontaneity: Characterising Modes of Thinking and Ways of Speaking in the Classroom

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8.1 Introduction

In this chapter, we present results of empirical studies for characterising zones of a conceptual profile combining the concepts of entropy and spontaneity of physical and chemical processes. We have dealt with two dimensions for the concept of energy, as it is usually approached in the natural sciences – transfer and distribution of energy. For the first case, transfer of energy, we proposed zones for a conceptual profile of heat (see Chap. 1; Amaral and Mortimer 2001). In the second case, distribution of energy, zones were constituted for the entropy concept associated to the spontaneity idea (Amaral and Mortimer 2004, 2006; this chapter).

We are aware that other dimensions are implicated in a wider comprehension of energy, for instance, availability, conservation, and storage. Nevertheless, it seems for us reasonable to consider that, starting from the two dimensions introduced in this chapter, important questions can be explored in the science classroom, such as the following: Why natural and artificial processes occur? How is energy transferred or modified in these processes? Comprehension about heat, endothermic, and exothermic mechanisms can contribute to understand the role played by energy in transformations of matter, and a profile of conceptions about entropy can be helpful to understand reasons for the spontaneous occurrence, or not, of physical and chemical processes,

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highlighting how energy can be distributed in matter. Long-term studies might progressively include other dimensions related to the energy concept in a similar framework.

Three zones were proposed for the conceptual profile of entropy and spontaneity. They are theoretically supported by ideas proposed mainly by Bachelard (1936/1978), Putnam (1995), and Van Fraassen (1993). The perceptive/intuitive zone comprises ideas about spontaneity related to immediate notions, perceptions, intuitions, and sensations, which are not organised in a coherent framework. They are strongly associated to the social and historical context in which spontaneous processes just occur naturally. In the empirical zone, the scientific point of view begins to be considered: Spontaneous processes can occur when we provide some physical conditions for that (such as appropriate temperature and pressure). Considering observation as being theory laden, the empirical zone can also be characterised by ideas related to the use of algorithms and mathematical equations in deciding if familiar processes are spontaneous or not. In this case, frequently, students handle exercises without knowing the meaning of mathematical symbols and conventions, which are used for practical purposes. In the rationalist zone, finally, scientific ideas about the distribution of energy in atomic-molecular dimensions and also about random spatial distribution of particles are found. Meaning for entropy and free energy of Gibbs can be reached starting from the particulate model of matter.

Finally, in this chapter, we analyse classroom situations and point out that in the science classroom, students can reveal ideas such as the ones identified in the above zones. These ideas when structured in a conceptual profile can be useful for the students to make distinctions among different modes of thinking and different meaning for scientific concepts associated to specific contexts. In this sense, conceptual profiles can be useful for teachers in planning and performing chemistry lessons.

In the analysis of classroom situations, we focus not only on the epistemological aspects of the content of the lessons but also on the discursive aspects in relation to the nature of the interactions between teacher and students. We then look for any relationships between these epistemological and discursive aspects.

The epistemological aspects are analysed in relation to the zones of a conceptual profile of entropy and spontaneity of physical and chemical processes. In the analysis of the discursive aspects, we draw upon the framework proposed by Mortimer and Scott (2003) for the analysis of the dynamics of classroom interactions.

The conceptual profile theory (Mortimer 1995, 2000) was initially inspired in Bachelard's (1936/1978) idea of epistemological profiles. Bachelard introduced the idea that the concepts of any individual are dispersed across different philosophical views, depending on their stage of development, emphasising the pluralism of culture and philosophy. Just as in Bachelard's epistemological profile, the conceptual profile is composed of different conceptual zones distributed according to a genetic order, with each zone having a greater complexity than the previous one. In subsequent developments, conceptual profiles went far from Bachelard's ideas by being integrated into a theoretical framework which treats science learning as learning the social language of school science through classroom discursive interactions. In this framework, aspects from different theories – the theory of language of the Bakhtin circle, Vygotsky's theory of the development of higher mental functions, and Mortimer and Scott's analytical framework (2003) for research into classroom communicative approaches – are integrated into a synthesis made coherent by several shared assumptions, characteristic of sociointeractionist or sociocultural approaches. The discussion about the theoretical bases for the conceptual profile theory is available in Chap. 1 of this book. In turn, a discussion of the methodology used to build conceptual profiles and apply them to classroom discourse analysis is available in Chap. 3.

As outlined in the discussion presented above, our focus here lies on the conceptual profile developed for the complementary concepts of entropy and spontaneity, which will be discussed later in this chapter. We will deal with ideas found in different contexts and sources – the history of science, the literature on science education, and the chemistry classroom – in order to develop zones for this particular conceptual profile. Then we will analyse some chemistry lessons to identify how these zones can emerge from the discursive dynamics produced by teacher and students in the classroom.

8.2 Constitution of the Zones of the Conceptual Profile for Entropy and Spontaneity: Theoretical and Methodological Aspects

8.2.1 Constructing the Zones of the Conceptual Profile

In order to construct the conceptual profile zones, we considered ideas drawn from different contexts – the history of science, science education research, and the actual science classroom – such that the proposed profile represents a broad and significant range of ideas concerning the concepts of entropy and spontaneity of physical and chemical processes. As discussed in Chap. 3, using multiple data sources to develop a conceptual profile is based on Vygotsky's idea that there are different genetic domains for the development of higher mental functions. In bringing together actual classroom data with ideas found in secondary sources of the history of science – considering aspects of the historical development of the concepts which relate to the discussions in the science classroom – we try to work with at least three genetic domains: the sociocultural, the ontogenetic, and the microgenetic. As discussed in Chap. 1, these genetic domains cannot be associated to a specific data source in a straight line; nevertheless, some sources seem to be more related to the emergence of ideas in a specific genetic domain than in others, for instance, concepts from the history of science tend to be related to the sociocultural domain.

8.2.2 The Concepts of Entropy and Spontaneity

In this research, the concepts of spontaneity and entropy are addressed from a perspective that fosters a deeper understanding of the physical and chemical transformations in the context of chemistry teaching and learning. Research on how students understand chemical reactions usually describes the students' conceptions related to important questions such as: What is a chemical reaction? To what extent do they occur? How fast? Do they absorb or release energy? Another important question related to this topic does not receive the same attention: Why does a chemical reaction occur? Since this question is very broad and refers to cases involving both the atomic-molecular structure of substances and energetic aspects of physical and chemical transformations, a way of restricting the focus addressed in this work is to reformulate the question as: 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 an understanding of the concepts of entropy and spontaneity.

For the purpose of developing a conceptual profile for entropy and spontaneity, we also sought the contribution of formal thinking about natural phenomena, which includes historical studies. Questions about the behaviour of matter and changes in nature date back to the period of the Greek philosophers and still appear in modern times, giving rise to a wide diversity of ideas. In discussing the historical development of aspects of spontaneity and entropy, we had no intention of making a deep study of the history concerning the various concepts related to the transformation of matter or exhausting the possibilities of philosophical analysis of those ideas. Rather, we intended to point to ideas that emerged in different periods of the history of science which, in our point of view, are involved in the genesis (Wertsch 1985) of the concepts of entropy and spontaneity and, also, have some relation to contemporary ideas in the context of science teaching.

We must consider one final point regarding the conceptual approach taken to spontaneity. Although strongly rooted in everyday experience, spontaneity is often not explicitly addressed as a concept in higher education physics and chemistry textbooks. However, all of these books use the word 'spontaneous' to characterise 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, which address the scientific conditions under which these changes may or may not occur. In that sense, our approach recognises that the process of scientific education should include more than simply transposing concepts developed in the academic context of science to the school context.

For the constitution of school knowledge, we consider not only the characteristics of the concept to be taught from the scientific point of view but also the necessary mediations which help to make the concept meaningful for the student. This involves pursuit of the relationships between scientific concepts and everyday reasoning in order to make the former relevant to the everyday experience that students already possess.

8.3 Procedures to Obtain and Analyse Classroom Data

The classroom data were collected in year 11 (students aged 16–17 years) at the High School of the Federal University of Minas Gerais, Brazil. The analysed teaching was included in the usual lessons of the teacher for the unit on thermochemistry. We analysed three sessions of 1 h and 40 min each: Two lessons were videotaped and transcribed in full, whilst another was analysed from field notes. Each lesson had three episodes selected for analysis, as representative of the interactions that took place and, also, because they allowed a synthesis of the whole teaching sequence. The observations focused on a group of five students, who were located closest to the camera. A wireless microphone was placed on their table to allow recording and transcribing their talk in the analysed episodes. The group chosen as the object of the research was proposed by the teacher, according to the criterion of their greater participation and interest in classroom discussions. From these data, we identified zones of the conceptual profile that emerged in the sequence of the three lessons, as well as performed a discursive analysis based on the framework proposed by Mortimer and Scott (2002, 2003), which is discussed in Chap. 3. This analytical framework includes five interrelated dimensions that focus on the role played by teachers in classroom discussions, considering their choices for actions and approaches to teaching. Here, for the analysis of classroom data related to the entropy and spontaneity concepts, we used four of these aspects: teaching purpose, the content of classroom discourse, communicative approach, and patterns of interaction.

8.4 Zones of the Conceptual Profile of Entropy and Spontaneity

As outlined earlier, the zones of the conceptual profile were developed using data obtained from the historical context, the science education literature on alternative conceptions, and observations from chemistry classrooms. We proposed three zones for the conceptual profile of entropy and spontaneity: the perceptive/intuitive zone, the empirical zone, and the rationalist zone. The zones of the conceptual profile comprise a set of ideas linked to three genetic domains, as referred to earlier: sociocultural, ontogenetic, and microgenetic domains. Ideas stemming from different sources were characterised by considering epistemological and ontological commitments underlying them, and the zones of the conceptual profile were proposed from a coherent set of those ideas. Here we present, in summary, the main ideas which characterise the proposed zones.

8.4.1 Perceptive/Intuitive Zone

The perceptive/intuitive zone of the conceptual profile of entropy and spontaneity consists of ideas which involve immediate perceptions, sensations, and/or intuitions that guide individuals in the construction of their notions according to the social and historical context in which they live and interact with their peers. In this zone, ideas and understandings can arise from empirical experience and personal interpretation of a phenomenon. In such situations, we do not deal directly with perceptions of entropy, since this concept involves a more scientifically elaborated understanding of the phenomena at stake. So, spontaneity is the focus of this zone, being related to ideas about phenomena that occur naturally, without outside interference.

From an epistemological perspective, perception is a way of accessing the external world that leads individuals to construct their notions (Putnam 1995). Building on ideas proposed by William James and Ludwig Wittgenstein, Putnam highlighted the role played by individuals and their forms of life (Anscombe and Rhees 1953) in the interpretation of objects and phenomena, bearing in mind that perception is informed by previous knowledge. Norman (1998) considered that, despite perception being informed by previous conceptions, it is not necessarily linked to an interpretative effort. In this work, we consider that in the perceptive/intuitive zone of the conceptual profile, ideas can emerge from perceptions of phenomena leading individuals to construct non-reflective, immediate, or intuitive conceptions. Such an immediate response is in line with Norman's idea of a non-interpretative response. In this latter sense, it is important to emphasise that conceptions supported by immediate impressions, sensations, and intuitions prompt subjective understandings of phenomena (Bachelard 1938/1996). According to Bachelard, these ideas are out of reach of any rational criticism, constituting a naïve realism, and once they are formed at an unconscious level, they are difficult to approach at an intellectual level. For Bachelard, these ideas are fundamentally different from those which emerge from the scientific context.

In relation to students' ideas about spontaneity discussed in the science education literature, we find conceptions about chemical reactions (changes of matter) that also suggest views of spontaneity. For example, Andersson (1986) proposed five categories for students' conceptions on chemical reactions. In the first category, he found that 10 % of the students justified the appearance of a thin and dark crust on copper water taps, over time, in terms of it being expected (it just occurs), without any consideration of the nature of the phenomenon. Rosa and Schnetzler (1998) analysed the results obtained by Andersson, highlighting that the students consider that the changes occur in materials because they are natural or expected to take place. These authors point out that students usually experience difficulties in understanding chemical reactions from an atomic-molecular perspective and only the phenomenological dimension tends to be used when they try to elaborate explanations for the changes.

Mortimer and Miranda (1995) also drew attention to students' ideas as they tried to explain iron rusting as a natural tendency of this material. Stravidou and

Solomonidou (1989), in turn, emphasised that students tend not to go beyond the description stage when examining chemical phenomena, because they are not aware of scientific concepts, but they recognise that changes are occurring and tend to form categories based on the phenomenon, using the visible aspects of the transformation of matter. From these research findings, we can recognise that some students tend to express intuitive ideas, based on their immediate perceptions of phenomena when dealing with chemical reactions or changes in matter. In this sense, understanding spontaneity of physical and chemical processes tends to be related just to the processes that can be seen to occur naturally.

In the classroom which was the focus of our research, students were not asked to perform experiments or to observe phenomena, but we investigated the classroom discussions relating to spontaneity and entropy concepts applied to some commonly known physical and chemical processes. For the perceptive/intuitive zone, representative ideas emerged mainly in the initial discussions, when students were not concerned with the scientific concepts to be studied. 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.

The ideas discussed above, and others not presented in this text (e.g. related to chemical affinity, Justi (1998), and transmutation, Andersson (1986)), reflect an understanding of spontaneity that is similar to the common sense, where people refer to any situation occurring naturally as being a spontaneous one. To reach an explanation for the occurrence of phenomena in terms of energy distribution, students must deal with the concept of entropy (Atkins 1984/1994). In this sense, the concept of entropy supports an understanding of spontaneous processes that goes beyond those occurring naturally (without external interference) and/or with macroscopic evidence. For example, the formation of water from oxygen and hydrogen can be considered a spontaneous process from the scientific point of view; however, it is not easy to visualise and requires certain conditions to take place, i.e. it does not occur ‘naturally’.

Generally, our first contact with phenomena is strongly influenced by everyday experience and language. The idea of spontaneity included in the perceptive/intuitive zone is not necessarily linked directly to the scientific view, but it is a mode of thinking deeply rooted in daily life. In putting forward these ideas in the school context, students are rarely asked to reflect on the differences between everyday and scientific views about phenomena. In daily life, usually, thoughts and actions are developed through these types of first approach to the phenomena and they become an automatic mode of thinking, which involves a lower cognitive effort for the individual. In the school context, we believe that it is important for subsequent learning that ideas from the perceptive/intuitive zone are discussed in an attempt to make students aware of the different meanings of concepts associated with different contexts and perspectives.

8.4.2 Empirical Zone

In the empirical zone of the conceptual profile, 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 ideas about the disorder of the system and a specific mathematical formalism which leads to decision making on familiar processes as if they were spontaneous or not. Here, besides the empirical view of getting data from technical instruments, we also consider as characteristic of an empirical approach the reference to observable events (for instance, a broken cup), values attributed to entropy representing a measure of disorder, and spontaneous processes occurring when there is some evidence for the increase in the entropy of the universe.

In the same direction, we also consider as typical of an empirical approach the use of conventions related to the entropy and free energy changes when processes are studied. This occurs by the application of algorithms and mathematical formulae in analysing physical and chemical processes without a complete understanding of the conceptual relationships involved in it. 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. The spontaneous occurrence of a process is indicated by a value which represents an increase in the entropy of the universe and/or a decrease in the free energy of a system. In terms of a mathematical expression, this is represented by $\Delta S_{\text{universe}} > 0$ (change in the entropy of the universe is greater than zero) and $\Delta G < 0$ (change in free energy is less than zero).

The entropy of the universe is defined by the expression $\Delta S_{\text{universe}} = \Delta S_{\text{system}} + \Delta S_{\text{surroundings}}$ (change in the entropy of the universe is equal to the sum of the change in the entropies of the system and of the surroundings). Usually, the value of the change in free energy is calculated from established data for temperature, T, change in the entropy of the system, ΔS_{system}, and change in the enthalpy, ΔH, according to the expression $\Delta G = \Delta H - T\Delta S_{\text{system}}$. So, if values for ΔS and ΔH are known, we can determine the temperature at which a given process will occur spontaneously. We consider ideas related to the use of these mathematical expressions and conventions strongly related to the empirical point of view when mathematical formalism is used just to inform empirical parameters about phenomena, which should be possible to get if we have a 'machine' to measure such parameters (Atkins 1984/1994).

According to Bachelard (1949/1977), empiricism is not far from theories because theories are implied in experience (technical materialism). For Norman (1998), empiricism is challenged in its central issues by the idea of observation as being theory laden. Norman considers that interpretation is used to justify what you see, and that the effort to interpret an experiment involves thought and time. From a similar perspective, Bueno (1997) presented Van Fraassen's ideas (1993) to the effect that an empirical theory must distinguish or choose a specific part of the world, establish a reference to that part, and, eventually, establish a substantial proposition about the world, to be represented by a model. This author outlines the constructive empiricism proposed by Van Fraassen, highlighting that it avoids the instrumentalism from the early empirical views by considering theories as families of models more than as instruments when they can be applied to real values (Bueno 2000).

Bearing in mind these philosophical points of view, in this work the empirical approach is characterised by ideas related to some experience with phenomena by physical or remote means (such as simulation or experience recovered from memory), in which technical instruments may have been used or not. This empirical experience is likely to be laden with scientific understandings or mathematical tools which lead students to construct ideas about phenomena from a scientific viewpoint. The steps of interpretation and analysis distinguish the empirical zone from the perceptive/intuitive one. The use of mathematical formalism without a complete understanding about implicated theories distinguishes the empirical zone from the next one, the rationalist zone.

Data on conditions under which processes occur can come from empirical measurements and symbolic representations or be given in tables. The point is that the student is taken beyond immediate perception of phenomena through 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 by scientific instruments, in science teaching and learning, teachers often encourage students to use these values as an empirical measure. This provides a first empirical approach to the concept of entropy.

Atkins (1984/1994) points out that the lack of a direct measure for entropy distances us from this concept, and he argues that a value for entropy could help to demystify the idea, making it less difficult to understand. According to him, entropy measurements would appear less complex than temperature and time, as displayed in thermometers and watches. Despite the absence of direct measurements, the application of the entropy concept in empirical situations can be made from values indirectly obtained for its change and using the established conventions and mathematical equations.

In the historical context, in order to reach more consistent explanations about the nature of phenomena and the identification of substances, analytical techniques became more rigorous and meticulous (Vidal 1986). According to Vidal, in the seventeenth century, ideas from alchemy had not been abandoned at all but technical procedures had improved mainly due to the use of chemical interventions for medical care. Furthermore, at different periods, ideas about chemical substances brought different contributions to the understanding of matter and its transformations. Changes could be investigated in terms of the substances present in matter and their properties by using more elaborated techniques, and so the reasons why substances react with each other were considered (Bachelard 1949/1977). In this sense, knowing the properties of substances and the conditions for change became essential and this led towards an empirical dimension. According to Bachelard, studies of chemical substances resulted in the evolution of chemistry as a recognised science.

After such studies, the relationship between substance and energy was investigated and changes of materials were studied from the point of view of energy exchange. Studies of chemical reactions also considered energetic aspects of the processes. The merging of two fields of knowledge – chemistry and thermodynamics – resulted in important contributions to the understanding of physical and chemical processes in energetic terms. In this context, the concept of entropy was proposed as a property of matter related to the capacity for transformation (Baron 1989), supported by Rudolf Clausius' (1850) studies. This concept emerged from a rigorous mathematical treatment given to the Carnot cycle by Clausius, focusing on ideas of conversion between heat and work. The interpretation of the physical meaning for the entropy concept was difficult mainly due to a complicated mathematical apparatus associated with the use of intuitive impressions (Laidler 1993). According to Laidler, the mathematical approach was predominant in the years after the concept of entropy was proposed.

Attempting to apply the principles of thermodynamics to chemical issues began 15 years after the proposition of entropy. Free energy was proposed by Gibbs in about 1870, as a result of studies related to chemical thermodynamics (Laidler 1993). In this sense, we can suppose that for some years, there was not a complete comprehension of the physical meaning of entropy applied to the thermodynamic models. This is akin to the use of formalism to support empirical ideas, but not rational ones, which is a common situation in the historical development of scientific models and seems to constitute one of the early origins for superficial approaches to the entropy concept even nowadays.

In several educational studies (e.g. Baron 1989; Bickford 1982; Stylianidou and Ogborn 1999), researchers have discussed and developed ways to approach entropy, which is considered a hard subject for teaching and learning. In a general sense, 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 chemistry teaching and learning context, questions about the spontaneity of physical and chemical processes are often addressed from the expressions for entropy and free energy, and then the mathematical approach is established. A conceptual discussion about symbols used in these expressions is rarely found in classrooms (Baron 1989; Ben-Zvi et al. 1993), and, normally, emphasis is given to the application of the mathematical expressions in order to determine the direction in which the processes can occur spontaneously.

Ribeiro and colleagues (1990) investigated how students in higher education used the criterion $\Delta G < 0$ to decide on the spontaneity of some chemical reactions. In general, the students knew how to determine the change in free energy, using data provided in a table, but few of them seemed to understand the meaning of free energy. Despite the results from applying the mathematical expressions, most students used the observable aspects of the reactions as the main criterion to judge spontaneity for the demonstrated processes. They got confused when data from empirical observation and mathematical evaluation were in disagreement. Granville (1985) pointed out that students often get confused about definitions for the entropy of the system and of the surroundings in the application of the expression for entropy. This author also found that they often overlook or modify the algebraic signs of the values found for the change in entropy, which contributes to the misinterpretation of the concept. These situations bring evidence for the use of mathematical formalism as an example of the empirical zone, and not of the rational one.

In the classroom investigated in this study, the students considered the increase of entropy for a broken cup, linking the idea of disorder to the larger number of pieces, thereby trying to bring the understanding of entropy to a macroscopic scale. These considerations were made from the point of view of the empirical referents. A second example involved the analysis of the vaporisation of water using values of temperature and pressure to define the physical conditions for which this process should be spontaneous (at 100 °C and 1 atm). The students' ideas were formed from the analysis of a particular chemical or physical process (such as the vaporisation of water), and discussions were conducted in attempting to reach explanations or generalisations. 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 scientific perspective, probably because 100 °C is not the temperature for the natural environment. In this sense, when students established conditions to consider vaporisation 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.

Subsequently in the lessons, the discussion about Gibbs free energy took place by focusing on the signs, symbols, and mathematical relationships present in the expression of free energy, as proposed by the textbook, which suggested an innovative pedagogical approach to science teaching. Nevertheless, we consider that in practice greater emphasis was given to the mathematics than to the conceptual approach in the classroom discussion. In this way, some questions made no sense. For example, a student asked about the possibility of absolute temperature being less than zero, suggesting a situation that has no empirical referent. Similar results have been revealed when students questioned about the spontaneity of iron rusting by incorrectly using values for changes in entropy and free energy, with no association with this familiar process in everyday life. We recognise that in such situations, students get into conflict about possible empirical evidence and mathematical formalism. In this sense, the empirical zone of the conceptual profile of entropy and spontaneity can be characterised by transitions between perceptive and rational ideas. So, ideas involved in this zone play an important part in the teaching and learning context.

We believe that ideas supporting the use of mathematical formalism can have a close relationship with rational thought; however, equations do not hold an explanatory power in themselves and cannot be considered equal to the latter. Ideas linked to the mathematical formalism are quite common in studies of entropy and spontaneity and, also, in other more complex concepts of thermodynamics. We have found that these ideas are important as a step forward to the rational understanding of entropy and spontaneity. Nevertheless, it seems to us that, in the school context, teachers and students very often do not go beyond this stage and students often do not reach an underlying understanding for the mathematical approach.

An important point to consider for the empirical zone of the conceptual profile is the nature of the concepts involved. Spontaneity is not a property of the system, but the concept of entropy provides a value associated with it. The empirical approach for spontaneity is often first addressed in school by observing processes that occur naturally in any context (daily life or school), although those cases do not include all the spontaneous processes, from a scientific perspective. Entropy cannot be measured directly by an instrument, but the values assigned to the entropy change are presented to the students as a measure of disorder, giving an empirical approach to it. We are quite sure that these points must be considered in attempting to make these two concepts easier for students' understanding. In the analysis of a particular empirical situation by using the concept of entropy, students can start a rationalisation process for the concept of spontaneity, providing a relationship between phenomena and theory.

8.4.3 Rationalist Zone

The rationalist zone includes ideas relating to entropy and spontaneity of physical and chemical processes that draw on the distribution of energy in an atomic-molecular level. We consider that in this zone ideas represent a deeper comprehension of the concepts, since students address entropy and spontaneity in relation to microscopic models of energy distribution of molecules. In this way, they can understand 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, when free energy change is lesser than zero ($\Delta G < 0$). In this case, spontaneity is related to the conditions to be provided in order to promote transformations in a specific direction. Spontaneity is related to a specific configuration for the distribution of energy in an atomic-molecular level, which provides conditions for the occurrence of processes in a specific direction. This concept of spontaneity is very different from the idea of natural occurrence of processes.

This zone of the profile draws on applied rationalism as proposed by Bachelard (1949/1977). In his work, Bachelard made a criticism of the rationalism from classical philosophy, considering it as a rationality built on a vacuum. He proposed applied rationalism to contrast with the traditional idea that rationality prevails in the isolated individual. Applied rationalism was proposed in conjunction with technical materialism. From this perspective, theory and experiment come together by considering that ideas arising from a theoretical approach tend to get their application and data obtained empirically tend to be organised by theories. On the one hand, in the academic context of science, a general aim is to develop new theories or models in order to explain and predict phenomena. On the other hand, in the school context, teaching and learning scientific concepts is the main goal, and practical work can support the discussion of a particular concept by using theoretical models. In this sense, applied rationalism sounds like an appropriate epistemological approach to characterise ideas in the rationalist zone of the conceptual profile.

Moreover, this approach can be related to Putnam's (1995) pragmatism. In the school context, theoretical ideas can be used to reach explanations about some empirical situations in order to understand generalisations offered by the scientific perspective. In this case, empirical phenomena and theories are interrelated and complement each other. This interrelationship involves questions of value and interpretation in the pragmatist sense proposed by Putnam (1995). Putnam argues that pragmatism does not deny the importance of the formal models applied to specific contexts, despite some authors who put pragmatism as standing in opposition to a theoretical approach. In the classroom, we realise that ideas on a conceptual understanding of entropy and spontaneity are developed when processes are discussed, considering the distribution of energy and organisation of the particles at an atomic-molecular level. 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). Theoretical models are used to determine the conditions for physical and chemical processes to occur spontaneously.

The discussion about the distribution of energy at the molecular level is a step towards the rationalisation 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. Ribeiro et al. (1990) found that few students used the ΔG values to decide whether a chemical reaction was spontaneous or not, and they also showed that few students can understand those values conceptually. Boo (1988) found that only 10 % of students in higher education were able to associate the occurrence of a chemical reaction with the decrease in free energy of the system and the increase in entropy of the universe.

In our classroom study, theoretical ideas about entropy and spontaneity were discussed to reach explanations about empirical situations and to understand generalisations 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 coloured 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. For example, in one moment of the lesson, a student proposed a hypothesis about the relationship between endothermic and exothermic processes and the change of entropy, based on a similarity between entropy and energy. Nevertheless, we realised 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. In this case, teachers play an important role in leading classroom discussions beyond the analysis of empirical conditions for spontaneity of the processes towards a more abstract mode of thinking, from an atomic-molecular perspective, seeking scientific explanations and generalisations about phenomena.

8.5 Analysis of Episodes from the Classroom Data

Data collected in chemistry lessons were analysed in relation to the epistemological and discursive aspects present in the students' and teacher's discourse, as well as in the textbook used in the classroom. The epistemological aspects were identified by using the conceptual profile zones whilst the discursive aspects were analysed according to the categories proposed by Mortimer and Scott (2002, 2003). The analysis was based on three episodes taken from each of the three lessons, in a total of nine episodes. The dynamic evolution of the epistemological and discursive aspects was analysed for the whole teaching sequence.

In this chapter, it is not possible to show the analysis for the entire sequence. Thus, we will present only data from two episodes in the second lesson. We consider that those data are illustrative with respect to the analysis carried out for the whole sequence of lessons. In Sect. 8.5.3 we will present some tables that summarise this analysis.

The second lesson was taught 7 days after the first. During that interval, the students had no lessons in chemistry and had to read some sections from the textbook – dealing with entropy of the system, entropy of the surroundings, and spontaneity – to be discussed in the second lesson. The students brought to the lesson written questions about the text and this task was part of their assessment process. Following the textbook, in the second lesson, they studied the entropy expression ($\Delta S_{\text{universe}} = \Delta S_{\text{surroundings}} + \Delta S_{\text{system}}$), including a discussion of definitions such as thermodynamic universe, system, and surroundings, which support and create a specific context for understanding the entropy concept. Initially, to further develop the scientific ideas about entropy, the teacher returned to a discussion started in the previous lesson about the equivalent distribution of energy for molecules, using a diagram. In the diagram, three possible arrangements of molecules in a system are proposed. The aim is to create an opportunity for the students to visualise different possibilities for the arrangements of molecules, which implies a specific distribution of energy among them.

For this chapter, we present the analysis of part of two episodes. Their numbering indicates that they are the first and the third episodes from the second lesson (2.1 and 2.3). For this analysis, conceptual profile zones were identified when they emerged during the discussion carried out in these episodes, so the zones can be considered as defining the units of analysis. Considering that episodes were transcribed in turns, when ideas related to a specific zone were identified in the classroom discussion, the turns at stake were used to create a segment of the episode, which was taken to be representative of that zone. The patterns of interaction were identified in terms of initiations, responses, feedback, prompts, and evaluation. The two episodes are presented below.

Episode 2.1: Discussion of Conceptual Aspects of Entropy (See the Convention Used in the Transcripts in Chap. 3)

Turns	Patterns of interaction
…	
19. Reading the text: So far, we consider only the entropy of the system, but we also have the entropy of the surroundings; the second law of thermodynamics can be written as follows: In any spontaneous process, there is an increase in the entropy of the universe. In the case of the systems we are studying, we can consider that the entropy of the universe is the sum of the entropies of the system and of the surroundings. Thus, a change in the entropy of the universe can be defined as $\Delta S_{\text{system}} + \Delta S_{\text{surroundings}} = \Delta S_{\text{universe}}$	
20. T: So far/There were some people who had some difficulties in understanding what is meant by the entropy of the universe (referring to the students' written questions from the beginning of the lesson)/ So what does it mean?/May I write that here?/(Pointing to the writing on the blackboard) Or what is the entropy of the universe?	Initiation
21. S2: The distribution of molecules in general}	Response
22. T: So…do you have….?	Feedback
23. S4: The general entropy}	Response
24. T: … the general entropy?/What is the universe?	Evaluation Initiation
25. S?: (Inaudible)	
26. T: Is it all the universe/all the stars/all the planets? Or is it a set of these things we have?//What is a system? For instance/I can heat some water/ok? I'm heating the water/that's right? (the teacher draws a container with water on the blackboard)/What is the system?	Initiation
27. S4: Water/	Response
28. T: The water is being heated here/ok? And what could be the surroundings?	Evaluation Initiation
29. S2: The region/	Response
30. T: It is the region around here/(pointing to the drawing in blackboard), is it right?	Evaluation Initiation

(continued)

(continued)

Turns	Patterns of interaction
31. A4: All right.	Response
32. T: The universe that is here/it is this set here/(pointing to the drawing)/ok? The system and the surroundings/isn't it? Surroundings of the system//so this universe is the set here, ok? (she draws a circle around the water container) Is everything all right? Is it clear/to who did not understand before? Ok?/Ok/(Is there) something else that I left? I mean/To consider whether the process is spontaneous or not/I cannot evaluate/for instance/I cannot only evaluate the system//I must also evaluate what is happening in the surroundings of the system/then I'll evaluate the entropy//how am I evaluating the entropy for this whole set here? It depends on the entropy of the system/it can decrease or increase/ and depends on the entropy of the surroundings/isn't it? Is it decreasing or increasing? Of course I'll have to evaluate it here/to check if the process is spontaneous or not/ok? Starting from this point, isn't it? Anything else for that piece? Who else would like to continue reading for us? Do you?	Evaluation Feedback
33. S4: Reading the text: If value for $\Delta S_{\text{universe}}$ is greater than zero/ the process is spontaneous. If $\Delta S_{\text{universe}}$ is less than zero/the process is not spontaneous/in other words/the process is spontaneous in the reverse direction. If $\Delta S_{\text{universe}}$ is zero, the system is in balance/the process has no tendency to occur in any direction.	
34. T: Ok/so look down/ΔS of the universe, isn't it? Greater than zero/ you have three situations//Less than zero/and ΔS of the universe … (she was writing on the blackboard)	Initiation
35. S2: Equal to zero/	Response
36. T: Equal to zero/So in this case here, you have the situation in which the process is going on in the system/but/I cannot fail to consider the surroundings//this process is spontaneous, isn't it? When ΔS…, isn't it? When change of the entropy for this set is less than zero/so this means that the process is not spontaneous/isn't it? Non-spontaneous//and when ΔS is equal to zero/the change of entropy is zero/it has no entropy change	Evaluation Initiation
37. S?: It is in balance/	Response
(The teacher continues the discussion by exploring students' ideas about what means when one says that a system is in chemical equilibrium, making a parallel with the figures that represent the distribution of energy at a molecular level.)	

During the second lesson, the teacher tried to apply mathematical conventions in order to determine if processes could be spontaneous or not. For instance, the teacher and students discussed about the vaporisation of water, first by using the mathematical formalism and then searching for physical conditions in which this process can occur spontaneously. Episode 2.3 illustrates part of this discussion.

Episode 2.3: Analysing a Process: Vaporisation of Water

Turns	Patterns of interaction
1. Reading the text: The process of water vaporisation is a process for which energy is demanded/it is endothermic/so the change of entropy of the surroundings is less than zero/that is/$\Delta S_{\text{surroundings}} < 0$. Remember that the change in entropy of the universe/$\Delta S_{\text{universe}}$/can indicate for us whether the process of water vaporisation is spontaneous or not.	
2. T: That's it/hold on//before you (continue to) read/Let's evaluate, ok?/To know if the process is spontaneous or not I have to know the value for this here, isn't it? (she points to the $\Delta S_{\text{universe}}$ written in the blackboard)/if positive/if it is negative/if it is equal to zero/ok?/Good/in that case/the vaporisation of the water/what is ΔS of the system? (she was referring to the previous discussion)/ greater than zero/in the same case//ΔS of the system greater than zero//what is about the surroundings?	Initiation
3. S3: Lesser	Response
4. T: ΔS of the system//of the surroundings/lesser than zero//and now?/is it spontaneous or not?	Evaluation Initiation
5. S2: It's not possible to know/	Response
6. T: F./C. (the teacher is demanding attention from two students engaged in a private talk)/is it spontaneous or not?//It's not possible to know…	Prompt
7. S2: If you don't know the temperature…	Response
8. T: But/If you know the temperature?	Initiation
9. S2: In this case you can.	Response
10. T: Let's do it in this way//consider 5 °C for the temperature/at this temperature/5 °C/is this process spontaneous?	Initiation
11. S2: But/you must know the…	Response
12. T: What? Is it spontaneous or not? And what about if you have 100 °C or a little more for the temperature?	Initiation
13. S2: Probably not/	Response
14. T: Is vaporisation of water NOT spontaneous at 100 °C?	Evaluation
15. S2: OH NO//it is totally spontaneous/	Response
(The teacher and students keep on this discussion trying to articulate empirical evidence and mathematical formalism for this process)	

8.5.1 Analysis of the Zones of the Conceptual Profile and the Content of the Classroom Discourse

8.5.1.1 Episode 2.1

In the previous lesson, the teacher had introduced the concept of entropy trying to build connections with the examples mentioned by the students and she also presented a diagram at the end of the lesson. The students had mainly associated entropy with the idea of disorder. At the beginning of the second lesson, the discussion came back to the diagram, but the students did not make the same association and other questions related to the atomic-molecular dimensions of matter arose. To understand the diagram, the students needed to deal with more abstract ideas. In facing a representation for molecules as balls, the students found themselves confused in identifying empirical entities (gas) as theoretical tools (molecules). The absence of empirical referents for the applied atomic-molecular model required a change in the students' way of thinking. In the sequence of the lesson, the mathematical convention which enables students to make decisions about whether a process is spontaneous or not was introduced and the teacher and students discussed the meaning of the terms in the expression $\Delta S_{\text{system}} + \Delta S_{\text{surroundings}} = \Delta S_{\text{universe}}$. Part of this discussion is illustrated in episode 2.1.

In this episode, from the textbook (turn 19), there is a statement about entropy in which one finds implicitly the thermodynamic definitions of the universe, system, and surroundings. These definitions are discussed in the text, which emphasises an expression of entropy in terms of an empirical generalisation – 'in any spontaneous process, there is an increase in the entropy of the universe' – building on the mathematical expression which states that the entropy of the universe is the sum of the entropies of the system and of the surroundings. We believe that the mathematical expression involved in the theoretical approach for the entropy concept does not necessarily support a deeper understanding of it, and thus, this form of thinking was characterised as an idea linked with the formalism of the mathematical approach to the concept – represented by the empirical zone of the conceptual profile – but not a rational one.

After the textbook reading, the teacher talked with the students about the definitions of thermodynamic universe, system, and surroundings, and, then, they discussed the expression of entropy. Questioned by the teacher about the meaning of 'entropy of the universe' (turn 20), students tried to explain this definition by starting from the previous discussion and offering ideas about 'the distribution of molecules in general' (turn 21), or trying to extend their current concept of entropy – 'to general entropy' (turn 23). The term 'general' seems to shape the meaning given by the students to the entropy of the universe, representing a cosmological understanding of the universe that is quite close to the common sense. At that point, the students' ideas about the universe are offered as immediate ones and can be related to the perceptual/intuitive zone. In turn 26, the teacher checked the students' conception about the universe by using two explanations for the latter: the cosmological and the thermodynamic. Then, she presented the idea of a thermodynamic universe, starting from a drawing of a system for heating water.

It seems interesting to highlight that the entropy concept could be applied to both the cosmological universe and the thermodynamic universe (Prigogine and Stengers 1997). In a general sense, differences between these definitions are not addressed in chemistry teaching, where only the thermodynamic universe is mentioned. In episode 2.1, by considering the students' previous conceptions about the cosmological universe, the teacher was able to clarify these differences, when she presented the thermodynamic universe (turn 32), starting from a discussion about a drawing of a small system for heating water (turns 27–31). Also, definitions of system and surroundings were discussed.

Following in the reading of the textbook (turn 33), the teacher dealt with mathematical conventions to evaluate the spontaneity of the processes (turns 34–36). Change in the entropy of the universe is introduced as a criterion to make decisions about whether processes occur spontaneously or not. The students easily accepted this mathematical convention, and this can be regarded as a progress compared to the spontaneity idea related to processes which occur naturally or 'alone'. Nevertheless, they do not seem to present a deep understanding of the mathematical formalism, although they were able to visualise changes occurring in the systems and surroundings.

The discussion between teacher and students in this episode included ideas characteristic of a transition between the empirical and the rationalist zones of the conceptual profile, and students began to express ideas close to those that are scientifically accepted. This indicates that students began to build a scientific understanding of the spontaneity of physical and chemical processes, with the support given by the teacher and the textbook. The empirical zone of the profile emerged when it was introduced through the mathematical expression for the entropy concept and the mathematical approach came to prevail in the discussions, but, as previously discussed, without being sufficiently understood by the students. Mathematical formalism first appeared in the discourse from the textbook and teacher and, at the end of the second lesson, students started to incorporate ideas related to it in their speech, when the discussions in the classroom ended.

8.5.1.2 Episode 2.3

In episode 2.3, the teacher and students are involved in a discussion on the vaporisation of water, a familiar endothermic process, trying to apply mathematical conventions as suggested by the textbook (turn 1). Starting from the statement $\Delta S_{\text{surroundings}} < 0$, some students had no difficulties to accept that $\Delta S_{\text{system}} > 0$, when this was stated by the teacher (turn 2), considering that the system absorbs heat from the surroundings. Nevertheless, they found that merely the use of mathematical conventions was not enough to decide if the process occurred spontaneously or not (turns 3–6), because opposite algebraic signals were attributed to ΔS_{system} and $\Delta S_{\text{surroundings}}$. It is important to highlight that most of the students probably had some empirical experience in which they could observe vaporisation of water taking place.

Challenged by this obstacle, a student suggested to consider the temperature as a parameter from which they could decide about the spontaneity of the process (turns 7–9). The teacher recommended to fix values for temperature – 5 °C and 100 °C – in order to analyse the occurrence of the process under these conditions (turns 10–13), but the students did not seem to understand the relationship between this parameter and the spontaneous occurrence of the process. Then, the teacher emphatically put in words the name of the process related to the value for the temperature 100 °C (turn 14), and this way of speaking seemed to recover from the students' memory aspects of their empirical experiences in recognising this familiar process (turn 15). Besides, the statement on the vaporisation of water occurring at 100 °C had already been mentioned in the textbook.

In this part of episode 2.3, we consider that students' speeches can be related to the empirical zone of the conceptual profile. However, differently from episode 2.1, the empirical zone emerged in the discussion about a familiar process and temperature was the criterion to make decisions about spontaneity. In this case, merely the use of mathematical formalism was not sufficient to determine the spontaneity of the process and the students demanded other parameters to continue the analysis. Some difficulties found by the students seem to relate to the complexity of putting together an analysis that they previously carried out in terms of mathematical formalism and their empirical experiences. Discussion in episode 2.3 reinforces the role played by the empirical zone of the conceptual profile in shifting students' ideas from a naive to a more complex understanding of the concepts involved.

8.5.2 Communicative Approach and Patterns of Interaction

In episode 2.1, the textbook reading took most of the time in the lesson and the teacher often reinforced ideas introduced by the textbook. Consequently, an authoritative communicative approach was predominant in this lesson, although one segment of turns (20–26) was more dialogic. Even though the textbook led the approach towards a noninteractive dimension, the teacher adopted a regular practice of interrupting the reading to promote students' participation and, also, some applications for the introduced concepts, turning the communicative approach more interactive.

The patterns of interaction also alternated in the classroom discourse. We identified a regular pattern with triadic format (IRE) and also chains appeared when the teacher tried to encourage the students in following with their claims and questions (e.g. the chain I-RS2-F-RS4-E-I, in the turns 20–24). The chains represent an attempt by the teacher to help students reach a meaningful understanding of the issues at stake.

In episode 2.3, the teacher adopted a communicative approach predominantly authoritative, because she intended to present the mathematical formalism for entropy, and interactive, considering that she often invited the students to participate in the discussions. The predominant pattern of interaction in this episode was I-R-E and also chains appeared when the teacher tried to check the students' understanding in the discussion on the vaporisation of water (turns 4–9).

Just as in episodes 2.1 and 2.3, the analysis of all the episodes in this second lesson (2.1, 2.2, and 2.3) showed that the approach to the content predominantly took the form of explanations and generalisations (empirical and theoretical ones). This result can be associated with the fact that the textbook reading and the teacher's speech prevailed in the lesson. In the previous lesson, the approach to the phenomena was carried out in terms of empirical descriptions, and in the second lesson, the teacher was involved in seeking an explanation for the observed situations. In this way, students should be introduced to the scientific models which could provide such explanation, so the teacher and textbook played an important role in this lesson.

8.5.3 Summarising the Analysis of the Episodes

In episode 2.1, the students seem to be organising/building their own notions, which are expressed in a vague way, and we do not find a well-defined format or genre for the discourse. Moreover, the teacher and the textbook introduce a school science genre in presenting the scientific view for the concepts, whilst students do not seem to recognise all the meanings or ways of speaking used by the teacher.

In Tables 8.1 and 8.2, we summarise the analysis for part of episodes 2.1 and 2.3, respectively, as showed in this chapter. For episode 2.1, there are six segments, each one corresponding to a conceptual profile zone or a transition between different zones. These segments, considered as units of analysis, express the changes in the conceptual profile zones underlying the speech. For the empirical zone, we have specifically indicated segments where students were dealing with mathematical formalism, in order to visualise different steps in the transitions that could be going on at this zone.

Following on this work, we present results from the analysis of the whole sequence, reached by using procedures that were similar to those used in the two previous episodes. Data are organised in tables to allow for a better visualisation. In these tables, categories are indicated by letters.

8.6 Some Results from the Analysis of the Three Lessons Sequence

The same analytical procedure illustrated for episodes 2.1 and 2.3 was performed for the nine episodes from the three lessons sequence. In this way, it was possible to obtain summary tables emphasising different aspects of the analysis. In this section, we present two of these tables related to the emergence of the conceptual profile zones and to the communicative approaches assumed by the teacher throughout the sequence. Finally, a third table will show a synthesis in which we point out some possible relationships between discursive and epistemological aspects identified in the analysis of the sequence of lessons.

8.6.1 Emergence of the Conceptual Profile Zones

In Table 8.3, we tried to represent the dynamics of the emergence and subsequent development of the proposed zones of the conceptual profile of entropy and spontaneity. The zones are identified as follows: perceptive/intuitive (PI), empirical (E),

Table 8.1 Summary of analysis: episode 2.1 as analysed in this chapter

Turns	Zones	Content approach	Teaching purposes	Communicative approach	Patterns of interaction
…					
19 (textbook)	Empirical (mathematical formalism)	Empirical generalisation	Developing scientific ideas	Noninteractive/authoritative	–
20–24 (students and teacher)	Perceptive/intuitive	Empirical description	Checking students' ideas	Interactive/dialogic	I-R-F-R-E
26–32 (students and teacher)	Empirical	Empirical description	Developing scientific ideas	Interactive/authoritative	I-R-E/I-R-E/I-R-E
33 (textbook)	Empirical (mathematical formalism)	Empirical generalisation	Developing scientific ideas	Noninteractive/authoritative	–
34–37 (teacher)	Empirical (mathematical formalism)	Empirical generalisation	Developing scientific ideas	Noninteractive/authoritative	I-R-E/I-R

Table 8.2 Summary of analysis: episode 2.3 as analysed in this chapter

Turns	Zones	Content approach	Teaching purposes	Communicative approach	Patterns of interaction
1 (textbook)	Empirical	Empirical explanation	Applying scientific ideas	Noninteractive/authoritative	–
2–5 (teacher)	Empirical (mathematical formalism)	Theoretical description	Checking students' ideas	Interactive/authoritative	2–7: I-R-E/I-R-P-R-
6–15 (students and teacher)	Empirical	Empirical description	Checking students' ideas	Interactive/authoritative	8–15: P-R-I-R-I-R-I – R-E-R

Table 8.3 Emergence of the conceptual profile zones in the sequence

Perceptive/intuitive zone (PI)	Empirical zone (E)	Rationalist zone (R)
First lesson		
Episode 1.1: Initial ideas on spontaneity and entropy		
PI (students)		
PI (teacher and students)		
PI (students)		
	Introducing the concept of entropy (teacher and textbook)	
	Introducing the concept of entropy (teacher and textbook)	
Episode 1.2: Analysing spontaneous processes: some examples		
	E (textbook)	
	E (textbook)	
PI (students)		
PI (teacher and students) ►	E (teacher and students)	
	E (textbook)	
Episode 1.3: Entropy, disorder, and distribution of energy in molecules		
	E (textbook) ►	R (textbook)
PI (students)		
	E (textbook and teacher) ►	R (textbook and teacher)
PI (students)		
		R (textbook)
	E (teacher and students)	
Second lesson		
Episode 2.1: Discussing conceptual aspects of entropy		
		R (textbook)
		R (teacher)
	E (teacher and students) ►	R (teacher and students)
	E (math formalism – textbook)	
PI (students)		
	E (teacher and students) ►	R (teacher and students)
	E (math formalism – textbook)	
	E (math formalism – teacher)	
Episode 2.2: Endothermic and exothermic processes, enthalpy, and entropy		
	E (textbook)	
	E (teacher)	
		R (teacher)
	E (teacher and students)/(students) ►	R (teacher and students)/(students)
	E (teacher) ►	R (teacher)
Episode 2.3: Analysing a process: vaporisation of water		
	E (textbook)	
	E (math formalism – teacher)	
	E (teacher and students)	
	E (math formalism – teacher and students)	
	E (textbook)	

(continued)

Table 8.3 (continued)

Perceptive/intuitive zone (PI)	Empirical zone (E)	Rationalist zone (R)
Third lesson		
Episode 3.1: Mathematical formulae for the Gibbs free energy		
	E (math formalism – teacher and students)	
PI (students)		
	E (math formalism – teacher and students)	
	E (math formalism – teacher and students)	
Episode 3.2: Applying Gibbs free energy expression to analyse processes		
	E (math formalism – teacher and students)	
	E (math formalism – teacher and students)	
	E (math formalism – teacher and students)	
	E (math formalism – teacher and students)	
	E (teacher and students)	
Episode 3.3: Solving exercises: the case of the iron rusting		
PI (students) ►	E (math formalism – teacher and students)	
	E (math formalism – students)	
PI (students)		
	E (math formalism – teacher and students)	
	E (math formalism – teacher and students)	

and rationalist zone (R). Each zone is represented along a different column and the ‘individuals’ (students, teacher, or the textbook) linked to the emergence of the zone are indicated in parenthesis. As mentioned before, we highlighted the use of the mathematical formalism in the empirical zone, considering it as a clue of a transition between zones.

The table shows the three lessons divided into the three analysed episodes, which are further subdivided into segments centred around a particular zone of the conceptual profile. The segments are made up by different numbers of turns, and each row of Table 8.3 corresponds to a segment of the episode which represents the prevailing ideas of a particular conceptual profile zone or a transition between zones. In this way, we can visualise different zones emerging both from an episode and from the whole set of them for one lesson or for the whole sequence of lessons.

The transitions between zones are indicated by an arrow, and they represent an articulation of ideas which are characteristic of different zones of the conceptual profile.

According to Table 8.3, initially in the first lesson day, the discussion included ideas which are characteristic of the perceptive/intuitive zone. At that point, the teacher had the intention of creating a problem and exploring students' ideas. Subsequently in the lesson, the concept of entropy was introduced from the textbook reading. The teacher led the discussion, showing some applications of this concept to common phenomena and processes. Then, ideas characteristic of the empirical zone arose.

Despite the movement started by the teacher, the subsequent discussion still involved students expressing ideas predominantly from the perceptive/intuitive zone. For instance, they only related spontaneity to naturally occurring processes. At the end of the lesson, again from the textbook reading, the concept of entropy was presented through a theoretical approach, introducing a scientific view of the spontaneity of the processes, and ideas from the rationalist zone emerged. It is important to highlight that the empirical and rationalist zones emerge from the teacher's and textbook discourse. These zones do not appear spontaneously in the students' speech, but only after the teacher's intervention, which was indicated in Table 8.3, at episode 2.2, by using a slash.

In the first lesson, we recognise the emergence of the three zones of the conceptual profile, but two of them were not addressed by the students. In episodes 1.2 and 1.3, we identify transitions from the perceptive/intuitive zone to the empirical one and from the empirical zone to the rationalist one, respectively, but it does not seem representative of a meaningful change in the students' mode of thinking.

In the second lesson, ideas characteristic of the empirical and rationalist zones came from the textbook reading and mathematical formalism was introduced to the students. In general, the discussion promoted by the teacher represented her attempts to engage the students in a scientific understanding of the concepts. With this intent, the teacher applied theoretical ideas presented by the textbook to different empirical situations. This teaching strategy seemed to promote transitions between empirical and rationalist zones, now also involving the students, and these transitions can be illustrative, thus, of how students began to express ideas closer to the scientific point of view. For example, the students tried to explain the spontaneity of chemical and physical processes by considering ideas about the distribution of energy. Support given by the teacher, based on the textbook, was crucial in this process, as we can see in Table 8.3.

The emergence of the empirical zone of the conceptual profile was closely related to the use of the mathematical expression for entropy, which was introduced by the textbook, and the mathematical approach began to prevail in the discussions. Ideas from this approach first appeared in the textbook and in the teacher's speech, and then the students included those ideas in their discourse throughout the classroom discussion. We can recognise that the students' speech is not yet autonomous, as it is often supported by the teacher in the discussion.

In the third lesson, the expression for free energy was introduced by the teacher, supported by the textbook, and the mathematical approach prevailed in the lesson. The teacher did not introduce a conceptual approach for free energy, neither does this appear in the textbook, and, thus, the rationalist zone did not emerge in the classroom discussions. After introducing the free energy concept, the students were asked to solve problems and discussion followed involving the teacher and the students working in small groups. In solving problems, the students mainly applied the mathematical expressions without really understanding the symbols they were using, and, thus, they brought ideas from the empirical zone. Ideas characteristic of the perceptive/intuitive zone emerged mainly in the discussion among students in the groups. This provides evidence that these ideas remain and coexist in the individuals even when they are introduced to scientific ideas about phenomena and, more than that, use them in classroom discourse.

In a general sense, throughout the whole sequence of lessons, we can recognise the emergence of the three zones of the conceptual profile, although some of them can be linked just to specific speakers. Firstly, ideas related to the perceptive/intuitive zone appeared when students were freely expressing their conceptions. Shifting in the zones can be recognised when ideas from the rationalist zone emerged mainly from the textbook and from the teacher's discourse. In order to build bridges between perceptive/intuitive ideas and the rationalist ones, the teacher brought up ideas centred in the empirical zone. When trying to apply rationalistic ideas to empirical situations, the students mainly handled these problems with ideas from the empirical zone, by using mathematical formalism without a deep understanding about the meaning of this symbolic language.

An interesting point to highlight is related to the empirical zone of the profile, which appears significantly in all lessons of sequence, and seems to represent a zone which could be useful to articulate different understandings of entropy and spontaneity. In a general way, the transitions between zones of the profile included the empirical zone. First, transitions were observed from the perceptive/intuitive zone to the empirical one and, later, from the empirical zone to the rationalist zone. These transitions are strongly linked to the role played by the teacher when she discussed spontaneous process and entropy, considering different points of view, including informal ideas of the students and scientific explanations.

8.6.2 Communicative Approaches in the Sequence

Table 8.4 illustrates different communicative approaches adopted by the teacher throughout the three lessons. The design is similar to that for Table 8.3, in which each line represents a segment of the episode related to a specific zone for the conceptual profile, and, then, a specific approach is identified for each segment. The communicative approaches are represented as follows: I/D (interactive/dialogic), I/A (interactive/authoritative), NI/D (noninteractive/dialogic), and NI/A (noninteractive/authoritative).

According to Table 8.4, the teacher predominantly assumed an interactive communicative approach throughout the whole sequence of lessons, something that characterises her personal teaching style. In addition, we can consider that the

Table 8.4 Communicative approaches in the sequence of lessons

Interactive/dialogic (I/D)	Interactive/authoritative (I/A)	Noninteractive/dialogic (NI/D)	Noninteractive/authoritative (NI/A)
First lesson			
Episode 1.1			
I/D			
I/D			
I/D			
			NI/A
			NI/A
Episode 1.2			
			NI/A
I/D			
I/D			
	I/A		
		NI/D	
Episode 1.3			
			NI/A
	I/A		
	I/A		
	I/A		
			NI/A
	I/A		
Second lesson			
Episode 2.1			
			NI/A
	I/A		
I/D			
			NI/A
I/D			
	I/A		
			NI/A
			NI/A
Episode 2.2			
			NI/A
	I/A		
	I/A		
	I/A		
	I/A		
Episode 2.3			
			NI/A
	I/A		
	I/A		
	I/A		
			NI/A

(continued)

Table 8.4 (continued)

Interactive/dialogic (I/D)	Interactive/authoritative (I/A)	Noninteractive/dialogic (NI/D)	Noninteractive/authoritative (NI/A)
Third lesson			
Episode 3.1			
	I/A		
	I/A		
	I/A		
	I/A		
Episode 3.2			
	I/A		
	I/A		
	I/A		
	I/A		
	I/A		
Episode 3.3			
			NI/A
I/D			
			NI/A
	I/A		
	I/A		

teacher was influenced by the pedagogical approach offered by the textbook. For instance, encouraging participation of students in classroom discussions is related to the pedagogical approach suggested in this resource. However, the segments related to the textbook reading were considered to be representative of a noninteractive/authoritative approach. In this sense, it is important to highlight that interactions were promoted by the teacher mainly starting from the textbook reading.

Two characteristics emerge from this analysis: (1) the majority of segments represent an interactive approach, and (2) authoritative discourse is predominant in the whole sequence. In trying to understand this finding, we turn to a short analysis of the different teaching purposes during the lessons. We are presuming that the adoption of a specific communicative approach is closely related to the teaching purposes (Scott et al. 2006; Aguiar et al. 2010). In the first day, the teacher had the purpose of generating a problem and exploring the students' ideas through dialogic interactions. In the second lesson, the teaching purposes were predominantly to develop and to apply scientific ideas, and were related to an authoritative approach, either interactive or noninteractive. In this lesson, dialogic interactions were limited, because when the students presented their questions and expressed their ideas, they had little influence in the development of the scientific perspective.

During the third lesson, when introducing the mathematical approach for the expression of Gibbs free energy, the teacher used an interactive/authoritative communicative approach. However, new opportunities for dialogic interactions appeared when the students worked in small groups, applying the mathematical expressions in order to make a decision on the spontaneity of processes. In this context, an authoritative position by teacher was assumed just to clarify doubts raised by the students.

This teacher had a tendency to emphasise dialogic interactions only in the beginning of the teaching sequence, when the students' ideas were explored. Afterwards, the teacher, with some small exceptions, ignored these ideas, as we see in episode 2.1. Although this is a strategy used by many teachers in school science, we still think that dialogic communicative approaches have their place in all the teaching sequence, and not only in the beginning.

8.6.3 Looking for Relationships Between Epistemological and Discursive Aspects

The analyses presented in Tables 8.3 and 8.4 were also carried out for the other three aspects of the classroom discourse, namely, the teaching purposes, content approach, and patterns of interaction. From the tables, it was possible to establish relations between modes of thinking, characterised in terms of the zones of the conceptual profile of entropy and spontaneity, and ways of speaking, characterised in terms of the discursive aspects. Table 8.5 suggests relationships between the zones of the conceptual profile and discursive aspects related to their emergence in classroom discourse.

The relationships are considered for the lessons investigated in this work. In this way, they cannot be taken as a generalisation for different situations in which epistemological and discursive aspects are brought together. In Table 8.5, we intend to show that the emergence of the different zones of the conceptual profile seemed to be more related to some aspects of discourse than to others. And the reverse is also true: Some aspects of discourse seemed to be more associated with the emergence of a specific zone than with others.

According to Table 8.5, the emergence of the perceptive/intuitive zone was related to an interactive/dialogic communicative approach, through which the students were freely allowed to express their ideas. The teaching purpose was to generate a problem or to explore the students' ideas. In this context, the content was addressed predominantly by the use of empirical descriptions.

When the teaching purpose turned to developing the scientific view of concepts, the ideas that predominate in the classroom discussion were those included in the empirical and rationalist zones. The content approach was made by theoretical and empirical explanations and generalisations. The teacher largely established an interactive/authoritative communicative approach, and triadic patterns of interaction and chains appeared equally in the speech.

Finally, ideas characteristic of the empirical zone of the profile were present in the entire sequence of lessons. This zone seemed to include most of the discursive aspects recognised in this classroom. However, an interactive/authoritative approach

Table 8.5 Relationship between epistemological and discursive aspects

Zones			
Discursive aspects	Perceptive/intuitive	Empirical	Rationalist
Teaching purposes	Generating a problem Exploring students' ideas	Generating a problem Exploring students' ideas Developing scientific ideas Applying scientific ideas	Developing a scientific view for concepts
Content approach	Empirical description	Empirical/theoretical explanations/generalisations	Empirical/theoretical explanations Theoretical generalisations
Communicative approach	Interactive/dialogic	Interactive/authoritative	Interactive/authoritative
Patterns of interaction	–	I-R-E/chains	I-R-E/chains

was predominant in the discussion of empirical situations. It is important to highlight that we have found different discursive aspects related to the empirical zone and this could be linked to transitions always involving the empirical zone. When the teaching purpose was to apply scientific ideas, the discussion involved the use of the mathematical formalism and empirical generalisations were predominant in approaching the content.

8.7 Final Remarks

In this chapter, we developed and presented a proposal for a conceptual profile of the concepts of entropy and spontaneity, when they are applied to understanding energetic aspects of chemical and physical transformations. In addition, the proposed conceptual profile was used to analyse the epistemological aspects of a chemistry classroom focusing on the dynamics of the discourse shaped by the teacher and students.

Characterisation of the zones of the conceptual profile was based on a study of the historical evolution of the concepts, a literature review of students' informal conceptions, and empirical data obtained in the classroom. At least three genetic domains – sociocultural, ontogenetic, and microgenetic – were addressed, in order to articulate the analysis of empirical data from the literature and those obtained in the classroom with aspects of the historical development of the concepts.

Acknowledging that the development of higher mental functions in each genetic domain is not caused by the same factor (Wertsch 1985), we did not intend to make comparisons between these different domains or to draw parallels between their contents, but, more broadly, we looked for an understanding of the genesis of concepts. This genesis allowed us to show the concepts in a dynamic process of formation and contributed to understanding some ideas that the students presented in the classroom. From this perspective, we highlight the importance of recognising how ideas from historical concepts can contribute to the development of student understanding, seen as a progressive process rather than being based on fixed concepts or phenomena.

Coherently with these observations, the conceptual profile can be used as an instrument for facilitating the teaching and learning of scientific concepts by making available to both teachers and students a synthesis from each of the zones. Identifying zones of the conceptual profile was shown to be a potential tool for the teacher in recognising and structuring ideas found in the high school classroom. In analysing the discourse, we found that students expressed ideas related to different contexts, and, therefore, different forms of thinking about entropy and spontaneity of chemical and physical processes were identified. However, the discussion in the classroom was predominantly oriented towards the scientific ideas through the work of the teacher, and so a particular view of reality was highlighted and constructed in scientific terms.

Despite the fact that scientific ideas tend to predominate in the school context, it is generally accepted that students construct meanings for scientific concepts from their previous experiences of everyday life, associated with the social and cultural contexts to which they belong. The fundamental importance of such previous experiences to learning should be considered for teaching purposes and those informal ideas can be made more or less prevalent in the classroom, depending on the pedagogical strategies used by teachers, as outlined in the analysis presented above. Generally speaking, as it has been exemplified throughout this study, there is a tendency to focus on the scientific point of view and not to acknowledge students' informal ideas in science lessons: Some zones of the profile are addressed, but not others, or some are preferentially addressed in the classroom.

In this regard, the attitude of the teacher and the pedagogical perspective adopted are crucial factors for the articulation of different ideas in the classroom. We should reiterate that scientific knowledge is often considered superior to other forms of knowledge, thereby discouraging discussion of different viewpoints. With these aspects in mind, conceptual profiles can be used in the classroom in the sense of suggesting, in a structured way, discussion of other points of view about the phenomena and concepts at stake, so as to put them in relation to the scientific perspective being taught.

From this vantage point, it is important to bring closer together scientific concepts and different forms of understanding, addressing a diversity of ideas also in the domain of science itself. The absence of an explicit discussion and comparison of these different approaches often prevents students from recognising transitions between different forms of understanding, which could be addressed through conceptual profiles.

Finally, we consider that the conceptual profile reveals a theoretical and methodological framework that allows not only to structure the ideas found in classrooms but also analyse classroom discourse dynamics, drawing on the analytical framework used in this investigation. From the analysis, we established relationships between epistemological and discursive aspects, for example, in finding that an interactive/dialogic communicative approach can support the emergence of ideas from the perceptive/intuitive zone. Thus, we consider that the conceptual profile theory could contribute to planning a more effective science teaching, which could lead to a deeper conceptual understanding.

In summary, we believe that the combination of the conceptual profile along with the analysis of discursive interactions provides a comprehensive modelling of teaching and learning actions, based on the way in which the full range of modes of thinking (the zones) and the full range of interactions (the four classes of communicative approaches) are explicitly recognised.

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