Science & Education 4: 267–285, 1995.

Conceptual Change or Conceptual Profile Change?

EDUARDO F. MORTIMER

Faculdade de Educação, Universidade Federal de Minas Gerais, Av. Antonio Carlos 6627, 31.270–901, *Belo Horizonte – MG, Brazil*

ABSTRACT: In this paper I draw an overview of a new model to analyse conceptual evolution in the classroom, based on the notion of Conceptual Profile. This model differs from conceptual change models in suggesting that it is possible to use different ways of thinking in different domains and that a new concept does not necessarily replace previous and alternative ideas. According to this model, learning science is to change a conceptual profile and become conscious of the different zones of the profile, which includes common-sense and scientific ideas.

To exemplify how the Conceptual Profile notion can help to understand the evolution of conceptions in the classroom I shall determine the different zones that constitute the epistemological and ontological profile of the concepts of the atom and of physical states of matter.

INTRODUCTION

The research on children's ideas about scientific conceptions in the last two decades has generated a constructivist view of learning that seems to be one of the major influences in science and mathematics education (Matthews 1992). Despite the great variety of different views that appears in the literature under the same label, there are at least two main features that seem to be shared by the different approaches: that "learning comes about through the learner's active involvement in knowledge construction" (Driver 1989, p. 481); and the pupils' previous and alternative ideas play a fundamental role in the learning process, as learning is possible only on the basis of what the learner already knows.

Corresponding to this model of learning there is model of teaching for dealing with students' conceptions and for changing them into scientific concepts: the conceptual change model. Proposed at first as a model to explain or describe "the substantive dimensions of the process by which people's central, organising concepts change from one set of concepts to another set, incompatible with the first" (Posner, Strike, Hewson & Gertzog 1982, p. 211), 'conceptual change' became a synonym for 'learning science' (Niedderer *et al.* 1991), which does not mean that there is a consensus about its meaning. As 'constructivism', 'conceptual change' became a label covering a great number of different and sometimes inconsistent views.

Despite the differences, there seems to be a generalised expectation in these views that the construction of a scientific concept would replace the initial view of pupils. The majority of the strategies in teaching science as conceptual change seems to have, explicitly or implicitly, an unreal expectation related to students' initial ideas: they should be abandoned or subsumed in the teaching process. In conflict strategies, this is a result of the process of solving a contradiction either between ideas and conflicting events or between different ideas related to the same set of evidence. In the analogy-based strategies, this is a consequence of the initial ideas becoming integrated and subsumed into a more powerful, scientific idea.

Only a few authors have explicitly recognised the impossibility of effecting this kind of change which results in the replacement of the student's initial ideas. Solomon has pointed out "that means should not be found to extinguish them (the everyday notions)" (Solomon 1983, p. 49–50). More recently Chi (1991) showed the possibility of the coexistence of two meanings for the same concept, which are accessed in the appropriate context. Linder (1993) argues that this coexistence is possible even within scientific concepts and illustrates this thesis with examples from mechanics, optics and electricity, where the classical and modern views of the same phenomena are not consonant. As a consequence, "science educators' depiction of learning should be extended so that less emphasis is put on students' existing repertories of conceptualisations and more effort on enhancing students' capabilities to distinguish between conceptualisations in a manner appropriate to some specific context" (Linder 1993, p. 298).

Moreover, some authors have tried to point out the difficulties of pupils in giving up everyday notions. The work of Galili and Bar (1992), for example, shows that the same students who performed well in familiar tasks about force and motion reverted to pre-Newtonian reasoning of 'motion implies force' in non-familiar questions. The authors conclude that "this 'regression' to naive views by the same subjects is further evidence of the complicated and sometimes inconsistent process of substitution of naive beliefs with new knowledge acquired in a physics class" (Galili & Bar 1992, p. 78).

In this paper I try to deepen this issue and to draw an overview of a new model to analyse conceptual evolution in the classroom, based on the notion of a conceptual profile. This model differs from conceptual change models in suggesting that it is possible to use different ways of thinking in different domains. It also suggests that, even in scientific domains, there are epistemological and ontological differences between successive theories. We can see this when we analyse the development of important ideas in science, such as the development of the theory of matter. Thus, it is necessary to prepare our pupils for a constantly variable enterprise if we are concerned with introducing them to different scientific domains. We shall exemplify this point with the different ideas about the atom that students have to learn at different stages of their studies. The new model also differs from some of the constructivist models of learning by showing that the process of construction of meaning does not always happen through an accommodation of previous conceptual frameworks in the face of new events or objects, but may sometimes happen independently of previous conceptions.

In developing my ideas I shall introduce the conceptual profile notion and discuss how this idea can be used to develop a strategy to teach the theory of matter.

DIFFERENT WAYS OF SEEING AND REPRESENTING THE WORLD

That people can have different ways of seeing and representing their world is not a new idea. Schutz, for instance, talks about a social word that is "by no means homogeneous but exhibits a multiform structure. Each of its spheres or regions is both a way of perceiving and a way of understanding the subjective experiences of others" (Schutz 1967, p. 139). To different realities, pertaining to specific social contexts, correspond different ways of knowledge. Berger and Luckmann (1967) emphasise that among the multiple realities there is one that presents itself as the reality *par excellence*: the reality of everyday life. "Compared to the reality of everyday life, other realities appear as finite provinces of meaning, enclaves within the paramount reality marked by circumscribed meanings and modes of experience" (Berger & Luckmann 1967, p. 39). When you shift your attention from this reality of everyday life to a finite province of meaning, for instance, to chemical knowledge, a radical change takes place in the way you conceptualise the reality. However, even when this kind of radical shift takes place, the reality of everyday life still makes its presence felt. The common language available for the objectification of the different kinds of experience is grounded in everyday life and even if you can shift to more sophisticated languages available in symbolic universes – such as mathematical language – you sometimes need to "translate the non everyday experiences back in the paramount reality of everyday life" (Berger & Luckmann 1967, p. 40). You also need to interpret the coexistence of these different sorts of realities.

The concepts and categories available in all the spheres of the word are held in an essentially similar form by a number of individuals, in a way that allow effective communication. These "collective representations" (Durkheim 1972) have a supra-individual characteristic and are imposed upon individual cognition. Vygotsky, drawing from this position (Kozulin 1990), pointed to the social dimension of the human mental process. Any higher mental function was external because it was social at one point before becoming an internal, truly mental function (Vygotsky 1978). Although in its biological beginning and in its intrapsychological end of development a psychological function appears as an individual process, Vygotsky shows that it passes through a stage of being a particular form of social collaboration (Vygotsky 1982; cited by Kozulin 1990).

Marton, drawing from the same idea of "collective representations", talks about "qualitatively different ways in which people perceive and understand their reality". These ways of understanding, are not individual qualities but categories of descriptions, the totality of which denotes a kind of collective intellect. "The same categories of description appear in different situations. The set of categories is thus stable and generalizable between situations, even if individuals 'move' from one category to another on different occasions." (Marton 1981, p. 193). Marton's ideas repose in the distinction between reality and the perception of reality. But they also have a component of content dependence, as "we cannot separate the structure and the content of experience from one another" (Marton 1981, p. 179). Marton suggests that we can use this superindividual system of forms of thought as an instrument for the description of the way people think in concrete situations and, from a collective perspective, as a description of thinking.

In Bachelard's *The Philosophy of No* (1968) there is a detailed explanation of different ways of conceptualising reality in terms of scientific concepts. Bachelard showed that a single philosophical doctrine is not enough to describe all the different ways of thinking when we try to explain a single concept. According to Bachelard, "one concept alone was enough to *disperse* the philosophies and to show that the incompleteness of some philosophies was attributable to the fact that they rested upon one aspect, they illuminated exclusively one facet of the concept." (Bachelard 1968, p. 34).

According to Bachelard, it should be possible for each individual to draw his or her epistemological profile related to each scientific concept. Despite the individual characteristics of the profile, as a result of an individual psychoanalysis of a certain concept, the categories that constitute the different divisions of the profile are superindividuals forms of thought, as they belong to a collective intellect.

Bachelard illustrated his notion with the concept of mass. The earliest form of the concept – the realistic one – corresponds to our everyday notions, strongly rooted in common-sense reasoning. Mass is attributed only to heavy and big things, and "corresponds to a rough quantitative appreciation – greedy, as it were, for reality. Mass is appreciated with the eyes" (Bachelard 1968, p. 18). These features act as epistemological obstacles to the development of the concept, since they block knowledge instead of summarising it. They also explain the difficulty for younger children in attributing mass to subtle materials, like air and other gases (e.g. Séré 1986; Stavy 1988, 1990).

The second level of the profile – the empiricist one – corresponds to a precise and objective determination given by the empirical use of scales. This clear, simple and infallible usage of an instrument substitutes the primary experience and gives the concept an empirical and positive clarity, even when the theory of the instrument is unknown.

The next level of the concept of mass – the rational classic – is related to its use within a body of notions and not merely as a primitive element of direct and immediate experience. With Newton, mass is defined as a relationship between force and acceleration. "Force, acceleration, mass establish themselves correlatively in a relationship which is clearly rational since it is perfectly analysed by the rational laws of arithmetic" (Bachelard 1968, p. 22).

Finally, with the advent of relativity, the concept of mass turns into a complex notion – the rational modern one – depending on a more complicated body of notions. The previous notion of mass as being independent of speed, absolute in time and space, and a basis for a system of absolute units gives way to a complicated function of speed. The notion of absolute mass has never had any meaning. Besides this, in relativist physics, mass is no longer different in kind from energy. "In short the simple notion makes way for a complex notion without, moreover, abrogating its role as an element. Mass remains a basic notion and this basic notion is complex" (Bachelard 1968, p. 25).

The epistemological profile, in each concept, differs from individual to individual. It is strongly influenced by the different experiences each person has, by their culturally different roots. Figures 1 and 2 illustrate two possible different epistemological profiles related to the mass concept. The height of each sector in a profile corresponds to the extension in which this 'way of seeing' is present in the individual's thought, which is defined by his or her cultural background and by the opportunities that the individual has had to use each division of the profile in his or her life. The higher the height of a sector the stronger this feature of the concept is in the profile as a whole. We have to be careful in interpreting this kind of representation, as the height of each sector is a roughly qualitative estimation. My own profile on the concept of mass (Figure 1) has the empirical sector as the strongest. This is related to my background in Chemistry and to several years of work in chemical laboratories, using scales as part of everyday activities. A hypothetical profile of a physicist (Figure 2) might be completely different. The empirical sector of his/her profile is weaker than mine, probably because he/she hardly uses scales in work routines. In compensation, he/she has a stronger rational sector, related to the experience of teaching Newton's laws. The modern sector of the physicist profile is also stronger than mine because he/she is more familiar with the theory of relativity and its implications.

One could argue that it is hard to believe that a chemist or a physicist would have a realistic concept of mass, attributing mass only to heavy and big things, appraising mass with the eyes. I would agree, since somebody could prove that a chemist or a physicist had never used mass in a metaphorical sense in his/her everyday language, he or she had never spoken about a 'mass of papers in the briefcase' or a 'mass of details to be worked out'. In these senses, mass is clearly realistic and it would be nonsense to speak about a *small mass* of details to be worked out. One important characteristic that may distinguish the chemist and physicist's profile from that of a novice student is that the former are conscious of their profile and can use each notion in the appropriate context, while the latter might not attain this consciousness.

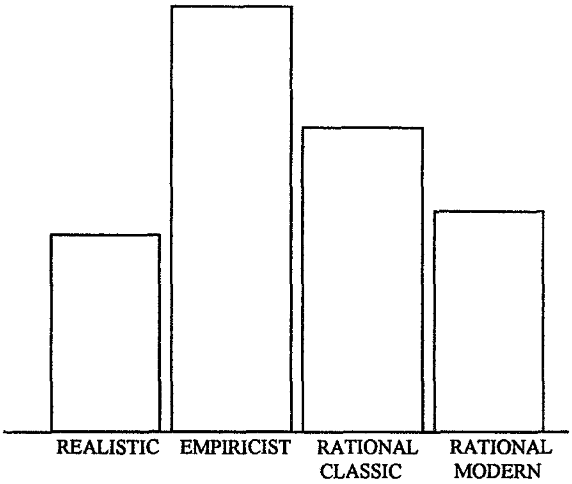

Figure 1. My epistemological profile of mass concept.

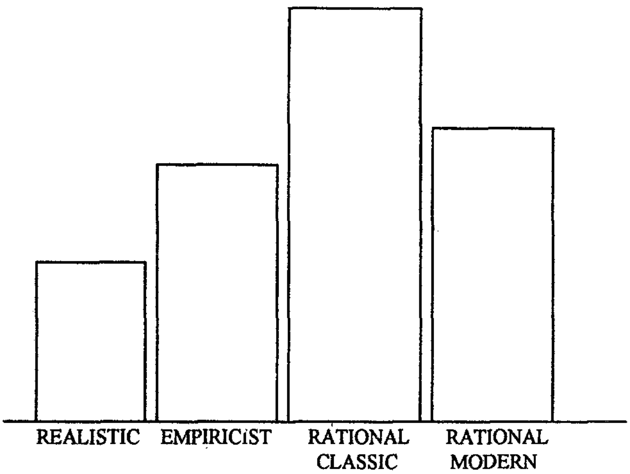

Figure 2. A physicist's epistemological profile of mass concept.

THE CONCEPTUAL PROFILE NOTION

I shall use the notion of 'conceptual profile' instead of 'epistemological profile' in order to introduce some features in the profile that differ from the Bachelard's philosophical notion, as my intention is to find a model to describe changes in individual thoughts as a result of the teaching process. The conceptual profile should have some similarities with the epistemological profile, such as hierarchies among the different zones, by which each successive zone is characterised by having categories with more explanatory power than its antecedents. Nevertheless, some important elements have to be added to Bachelard's notion. The first one is the distinction between the epistemological and ontological features of each concept. In spite of dealing with the same concept, each zone may not only be epistemologically but also ontologically different from others, since the conceptual features change as you move through the profile. As I will show later, the atom as a quantum object does not belong to the same ontological category as the classical atom, a sort of basic block from which matter is built. This feature has special importance as many of the difficulties in learning science concepts have been identified with the difficulties in changing the ontological categories that the concepts are assigned to (Chi 1991).

Another important feature of the 'conceptual profile is that its 'non-scientific levels are not constrained by philosophical schools of thoughts, but by the epistemological and ontological commitments of individuals. As these individual characteristics are strongly influenced by culture, I may try to define a conceptual profile as a "superindividual system of forms of thought" (Marton 1981) that can be assigned to any individual within the same culture. Despite the differences between individual profiles, the categories by which each conceptual profile is drawn are the same. The conceptual profile is, therefore, context-dependent, since it is strongly rooted in the individual's distinct background, and content-dependent, since it refers to a particular concept. But at the same time its categories are context-independent, as within a culture we have the same categories by which the zones of the profile are determined. In the western, industrial civilisation, the scientific divisions of the profile are clearly defined by the history of scientific ideas, as part of the Popperian 'third world' (Popper 1972). The pre-scientific zones for many concepts are also clearly defined as a consequence of the last two decades of intensive research on students' alternative conceptions, that have identified the same sort of conceptions related to the same scientific concept in different parts of the world.

Taking the notion of Conceptual Profile (CP) into account, the problem of learning and teaching science may be considered in a new way. It is possible to teach a concept at a certain level of the profile without reference to a less complex level since they are epistemologically and ontologically different. In this sense, the learning process may be thought of as the construction of a body of notions based on new facts and experiments presented to the students in the teaching process. The new concept does not necessarily depend on the previous ones and could be applied to a new, different domain. Only when the alternative concept forms an epistemological or ontological obstacle to the development of the concept at a more complex level is it necessary to deal with this contradiction, something that could happen at any time during the teaching process and not only at the beginning. Overcoming this contradiction means finding a way to explain it, which is possible at the more complex level of the concept that has been taught, but does not mean abandoning the old way of seeing it, which continues to form part of the individual profile.

To plan teaching according the CP we have to determine the different divisions of the profile for each conception and identify the epistemological and ontological obstacles. There is an ample source of information concerning alternative conceptions in the literature that can be used to identify the features of the concept at its elementary level and to establish which of these features are obstacles to the development of a new zone of the profile. The history of science is another important source of information, not only for this sort of elementary level but also for the more developed levels of the profile.

As each concept may have different features and different profile divisions, there is no general rule or sequence of steps that can be applied to any concept, as suggested by some constructivist approaches. Instead of universal steps – for instance, elicitation of previous ideas, their clarification and exchange within the class group, exposure to conflict situations and construction of the new ideas, followed by review of progress in understanding – the conceptual profile notion suggests that the teaching process and its steps depend on the specific epistemological and ontological features of each profile zone of the concept to be taught.

Nevertheless, we can consider two distinct moments in the learning process. The first corresponds to the acquisition of the concept at a specific profile level and depending on the nature of the epistemological and ontological obstacles identified in the previous zones of the conceptual profile. The teacher's role is not only to monitor an adaptive process, by pointing out new evidence and showing relationships between theory and experiment. The teacher also has the fundamental role of identifying the obstacles as well as of trying to minimise and lower them, to help overcome them. In this way, he or she performs a set of different functions that cannot be arranged in a sequence of steps: to make the agenda explicit; to address the obstacles and the epistemological features of the scientific knowledge to be learned; to reduce the degrees of freedom that the pupils have to manage in the task of recognising and overcoming these barriers that are interposed between their notions and the new one; to generalise the new ideas and give the students the opportunity to generalise them; and to call the students to reflect on their own ideas, to compare these ideas with the scientific ideas, and to be aware of the development of their ideas.

The second important moment in the learning process is that of the pupil achieving consciousness of his/her own profile, which allows the comparison between different areas of the profile as well as an evaluation of their relative power. In this process, the students will be conscious of the limitations of their alternative conceptions but without giving them up. The same process will happen at a more advanced level, when students have to restrict the domain of an old scientific concept as they learn and become aware of a new level of its profile. This is what happens, for example, when they learn a quantum mechanical view of matter and can see the limitations of a classical atomic view.

The process of achieving consciousness of one's own conceptual profile is not an easy task in the learning process. It involves some kind of abstraction in which the mind reflects on itself. In a Piagetian view (Piaget 1977), it depends on the capacity of the individual to operate at a second level, operating upon an operation, which means the individual has to acquire the capacity to analyse his or her thoughts and never more remain submerged in his or her mental functions. Once the individual acquires this ability, he or she can perform this analysis and use criteria like coherence, logical consistency and accordance with experience. Besides this, he or she is more flexible and open to other ideas, and can compare them with his or her own ideas, criticise and overcome his or her own ideas when necessary.

Vygotsky, expresses himself in the same way, and uses "consciousness to denote awareness of the activity of mind – the consciousness of being conscious" (Vygotsky 1962, p. 91). According to him, "consciousness and control appear only at a late stage in the development of a function, after it has been used and practiced unconsciously and spontaneously. In order to subject a function to intellectual control, we must first possess it" (Vygotsky 1962, p. 90).

To attain this level of consciousness students have to experience a process of generalising the new concepts in a large number of different situations. In this process the new concept can acquire stability to be employed in a new situation, even a potentially disturbing one. Disturbances (in a Piagetian meaning, Piaget 1977) and problematic situations play a fundamental role in the process of achieving consciousness. Claparède, in 1946, already called attention to this problem with his 'law of achievement of consciousness': "the more the individual's behaviour involves an automatic and unconscious use of a process, a relationship, or an object, the later he/she achieves consciousness of this process, relationship or object." (Claparede 1946, p. 57, author's translation). In other words, to acquire consciousness of a concept we must use it in new and problematic situations, that demand its conscious use. In these new situations there is a strong tendency for a student to use previous conceptions, that belong to the non-scientific level of the conceptual profile. This happens because the previous conceptions are more familiar to him, and generally it is easier to relate something new to a more familiar conceptual structure than to a new one, that has just been constructed. To acquire stability, the new concept has to be submitted to a range of disturbances and problematic situations. In this process the students should acquire consciousness not only of the new scientific concept but also of the relationships between the different levels of their conceptual profile, and when it is more convenient to use one or another of the levels.

The teaching process includes, therefore, the explicit use of alternative ideas, its criticism and the evaluation of its domain. Nevertheless it does not include the suppression of alternative ideas, neither does it raise or lower the status of a person's conception, understood as "the extent to which the conception meets the three conditions (to be intelligible, plausible and fruitful)" (Hewson & Thorley 1989, p. 542). According to the CP we cannot lower or raise the plausibility or the fruitfulness of some conception, but only show in what domain it can be considered as plausible and fruitful. No one can survive without common sense. Even a professional scientist uses phrases such as "shut the door and keep the cold out". There is evidence to show that physicists use naive notions to make predictions in everyday life (McDermott 1984), and we have already pointed out some of these situations relate to the concept of mass. This way of viewing the world is largely incorporated as a cultural feature of everyday life. A person can acquire the capacity to criticise its meaning in the light of more sophisticated ways of thinking. However, to suppress the alternative conceptions sometimes means suppressing common-sense thought and its mode of expression, everyday language, which is the most comprehensive way of sharing meaning in a culture and permits communication between all the various specialised groups that share the same mother tongue. To suppress it means suppressing the possibility of different groups sharing meaning within the same culture.

APPLYING THE NOTION OF A CONCEPTUAL PROFILE TO TEACHING "THE THEORY OF MATTER"

I shall attempt to apply the general ideas developed earlier, to the teaching of two concepts related to the theory of matter: the more elementary atomistic concept of matter and the physical state of matter. To do this I shall search the categories for a conceptual profile of these concepts, using the history of science, the literature about alternative conceptions and the results of my study in the classroom.

Atomism was chosen because it is a central idea in chemistry with a rich history of successive models increasingly suitable for experiments. A new model, in the history of atomism, superseded its predecessor based on new experimental evidence. The old models, however, remain helpful to explain some specific phenomena. In this sense, there is a number of alternative atomistic models that can be used in different contexts. It is also possible to discern a number of non-scientific atomistic conceptions among individuals from a great number of works in the literature. Atomism is, therefore, a concept with a large and clear conceptual profile. Moreover, atomism is a model and, in that sense, a construct with no direct link with observations. The history of atomism in the nineteenth century shows that there was no definite evidence of the existence of atoms and that only someone who had taken the atomistic route could see atoms anywhere. In this respect, anomalies, conflicts and critical experiments seem to be ineffectual in keeping continuous and other alternative ideas about matter in check. On the contrary, these alternative ideas seem to be coherent and plausible, possessing high status for the students. However, these ideas present some epistemological and ontological obstacles to the development of scientific atomism, even at an elementary level. It is possible to identify these obstacles in the analysis of the conceptual profile of the atom and to plan the teaching taking them into account.

The other concept, physical states of matter, has a number of different features. It has strong roots in empirical experiments and even in the empirical dealings of everyday life. There are several studies in the literature showing that children are able at an early age to conceptualise solids and liquids in some way and to use these concepts to classify materials. Moreover, these primitive ideas of liquid and solid, like 'solid is rigid and hard', 'we can pour liquids', 'liquids have water', etc., are helpful in dealing with liquids and solids in everyday situations. The construction of a new, scientific idea, must explain the old one but not suppress or lower its status. If this happened, the students would have a number of problems in their everyday life, spilling liquids and colliding with solid objects. In that case, the teaching process has to show the boundaries of the primitive concept, through situations where they do not function, like colloidal suspensions and liquid crystals.

CATEGORIES FOR A CONCEPTUAL PROFILE OF THE CONCEPT OF THE ATOM AND OF THE PHYSICAL STATES OF MATTER

The first zone of the atomic profile is a realistic one, and it is characterised by the absence of any discontinuous notion of matter. This zone is characterised by a negation of atomism and its main obstacle is of the negation of the possibility of the existence of a vacuum. A student who only has this notion of matter represents it as continuous, without any reference to particles.

Related to this concept of matter, there is a realistic notion of the physical states of matter closely linked with external appearances and sensible features of materials. Our pupils showed the same variety of realistic views that appear in the literature: solids are hard, thick; it is possible to touch and to hold solids; liquids are soft; it is not possible to hold liquids, they drain off; liquids are wet, they contain water; gases are invisible; it is not possible to touch or to feel a gas; gases spread in the atmosphere (see, for a comparison, Stavy & Stachel 1985; Stavy 1988).

The second zone of the profile I call substantialist atomism. Substantialism is a relevant feature because it leads to the conclusion that despite using particles in their representations, the students think of such particles as matter grains that can dilate, contract, change state and so forth. Students, thus, made an analogy between the behaviour of the drawn particles and that of the substances. They are not referring to the atom, as a scientific concept, but to grains of matter that show macroscopic properties. This analogy between the macroscopic and the microscopic worlds is the main epistemological obstacle for students whose concepts can be classified in this zone. Moreover, the fact that they use particles in their representations of matter is no guarantee that they believe in the existence of the vacuum between them. This is particularly important in the sense that someone in this area does not necessarily overcome the obstacle of the previous one. There was a similar episode in the history of Science. Since the 17th century, mechanicist philosophers have tried to explain matter transformations using material particles, reviving the atoms of Leucippus and Democritus. However, there was no consensus about the nature of particles: were the particles true atoms (from Greek, *indivisible*) separated by a vacuum – as stated by Gassendi and later by Boyle and Newton, among others – or were they separated by other ever smaller particles, at the smallest limit of which are infinitesimal particles – as Descartes, followed by other philosophers believed? (Van Melsen 1952).

There is no concept of the physical states of matter that corresponds to this substantialist atomism. The second zone of the profile of such a concept is related to empirical properties that allow one to define solids, liquids and gases in a more precise way. This concept is usually taught in schools, in the early grades, and uses two empirical properties to classify materials: the shape and the volume. According to such a concept, solids have definite shape and constant volume; liquids also have constant volume, but their shape is variable; and gases have both shape and volume variable.

The concept of the atom has no corresponding empirical area and the difficulties of accepting it in the 19th century were related to the absence of empirical evidence. Several important scientists in the 19th century were sceptics regarding its validity and some of them were in strong opposition to it. Faraday, for instance, whose empirical works made important contributions to the development of the atomic hypothesis, had serious reservations about it based on empirical reasoning. He demonstrated the impossibility of providing a coherent explanation for the existence of conductive and insulating materials in the light of this atomic hypothesis. According to Faraday, this hypothesis had postulated that each atom was separate from the others and the only continuous component of matter was empty space. As he reflected on the need of a continuous medium to allow electricity to flow through matter, Faraday asked how empty space could have a dual nature, being a conductor in the conductive bodies and an insulator in the insulating ones (Faraday 1844). These difficulties in the history of science help to understand some of the difficulties in the teaching process, related to the lack of empirical evidence for an atomistic hypothesis.

The third zone of the atom's profile corresponds to a classic notion of the atom as the basic unit of matter, which is conserved during chemical transformations. The atom is a material particle and its behaviour is governed by mechanical laws, like any other body. The substances are made up of molecules that result from the combination of atoms. Atoms of the same type have the same mean atomic weight.

In my study I am concerned with this third area of the atom's profile, as I am interested in finding ways of teaching the theory of matter at an elementary level. To teach this concept we have to identify its categories and use these categories to expand this section of the profile, by creating a 'fine structure' of the conceptual spectrum. One important category to be added to discontinuity and absence of substantialism is the conservation of mass in the transformation of matter. The lack of conservation seems to be easier to overcome than the idea that 'nature abhors a vacuum' and than 'substantialist atomism'. I believe there might be an epistemological obstacle to the construction of the concept of the atom if students did not use conservation reasoning in any context. However, such is not the case. Students in the age 14–15 use conservation reasoning in several ways. The question is only concerned with the transfer of this reasoning to a new situation.

The three categories (continuity/discontinuity; substantialism/non-substantialism; absence/presence of conservation of mass) were sufficient for an analysis of the atomistic ideas showed by students before teaching. As in many studies in the literature, our students did not use the other categories that characterise classical atomism: motion-energy; interaction-arrangement.

The third zone of the profile of the physical states of matter is supported by a generalisation that is not an external characteristic of materials but has to be constructed as an explanatory model. In such a definition there are mutual aspects among the solid, liquid and gaseous substances, that is, they are made of particles. What makes solid substances different from the liquid and gaseous ones is no longer the external variation – an extrinsic and sensible feature – but an intrinsic one, belonging to a broader conceptual system that allows us to identify similarities between materials that seem to be so diverse. This transition from external features, linked to strong sensible aspects, to internal features, linked only to imaginary models, is a great epistemological obstacle to be overcome when teaching.

These intrinsic features of the classical atomic model, together with discontinuity, allow for an analysis of the behaviour of matter, leading to a more sophisticated concept of the physical states of matter than the realistic and empirical ones. This 'internal' concept constitutes the third zone of its profile. According to such a model, particles have an intrinsic motion associated with kinetic energy, and must be arranged in different ways in the three physical states, which are associated with different interactions between particles in each state. It follows that solids are arranged in a very orderly fashion because of the strong interaction between particles, which occupy fixed positions in a crystal. Liquids keep their particles packed together, but they are in a disordered arrangement, which means that interaction between them is weaker than that of solids. In the gaseous phase, particles have a minimum interaction and because of this they do not come together and have more motion than those of liquids, besides being individual. If gaseous molecules do not absorb light in the visible region of their electronic spectrums, one might expect this gas to be invisible.

This latter feature allows for criticism of the realistic and empirical concepts of the gaseous phase that includes clouds, fog and the steam resulting from boiling water in a kettle, as gaseous materials. Moreover, there is a need to work with another category of materials, namely, with aerosols, so as to classify these types of materials.

It is important to realise that classical atomism still has some 'realistic' and 'substantialist' characteristics, as a legacy of its mechanicist origins. Despite the epistemological difference between classical atomism and the other two areas of the profile, all these conceptions consider the atom as a kind of material thing, a basic block from which substances are built. In this sense, all these 'atoms' belong to the same ontological category. The main difference is that in a classical and rational view, we cannot attribute all material behaviour to atoms, just because some forms of behaviour (such as melting, boiling, dilating) are a consequence of the motion of atoms, molecules or ions in a vacuum and of the interaction between them, which can vary as the energy of the system is modified. Consequently, an individual atom does not show properties like boiling or melting points, that are interpreted as a result of aggregating a great number of them in macroscopic amounts. Nevertheless, a classical atom shows some other material properties like mass, volume, radius, etc. Then, it is a material thing that belongs to the ontological category of substance. The atom only changed to another ontological category with quantum mechanics, which began to see atoms not as material particles but as quantum objects.

I might not have been concerned with other areas of the profile of the atom concept as I am interested in teaching it at an elementary level. However, it is important to identify the general direction of change in the concept, so as to avoid reinforcing some epistemological and ontological obstacles to its understanding at a more advanced level. It is impossible to avoid this problem completely, since the classical view of the atom possesses some intrinsic features that are obstacles to the construction of a quantum view of the atom. This is inherent in the notion of obstacle, a characteristic of knowledge. What is a new idea today, is fated to be, in the future, an obstacle to the resolution of a new problem. This provisionality of knowledge obliges us to think about teaching as a change in the conceptual profile and not as a replacement of everyday notions by scientific concepts, which will have to be replaced by more advanced concepts.

In the logic of the replacement of concepts, it would be useless to teach classical concepts, since they are not 'scientific concepts' in the light of modern science.

The new zone of the atom's profile is a consequence of the quantum mechanical treatment of the atomic system. The application of Plank's elemental quantum of action to the atom, made by Bohr in 1913, initiated the transition from the classical to the quantum view of the atom. In Bohr's atom this new idea coexisted with classical ideas about particles in orbit. However, the new atomic view that emerged from the quantum theory at the end of the next decade broke drastically with the mechanical concept of the atom as a material particle. The atom as a quantum object belongs to another ontological category. It is no more a material particle, but a kind of object better described by mathematical equations than by analogies or models. The most popular version of quantum mechanics is precisely the one postulated by Schrodinger, which attributes wave equations to electrons. The appeal to familiar things like waves does not decrease the complexity of quantum reality, since we attribute wave properties to material particles.

The quantum mechanical view of atoms has two important implications for the teaching of a classical view. The first is that it implies a dialectical overcoming of the continuous-discontinuous contradiction. The quantum object has the properties of continuous things (waves, fields, etc.) and of discontinuous things (particles). According to Toulmin, "Physicists can discuss quite seriously whether so-called 'fundamental particles' might not be replaced by mathematical singularities in fields of force – a conception having more in common with the continuum theories of the Stoics than with the unvarnished atomism of Democritus" (Toulmin 1961, p. 105). The problem is simply related to how each scientific culture uses its conceptual profile. For chemists, the classical, atomistic and discontinuous view is really fundamental. The whole of our molecular universe is represented as such. A chemist can imagine a molecule as a set of mathematical singularities in fields of force. However, when planning a synthesis he or she is more concerned with particles as material entities, that can be added to or removed from a reagent to obtain a final compound.

The second implication of quantum mechanics to the teaching of classical atomism is the role of models and analogies. The difficulties of interpreting results from quantum mechanics are related to the impossibility of translating them into our familiar world of material objects and events. There is no direct link between theoretical elements and physical reality, at least in a classical view of physical reality (for an interesting debate of this point see Einstein, Podolsky & Rosen 1935; Bohr 1935). As a consequence, in classical atomism we cannot work with models and analogies as definitive truths about reality, but as provisional and incomplete views that are merely isomorphic with reality. The model is essentially a construction, an ever-provisional construction, dependent on the answer that reality gives to its prescience. When teaching classical models, we must be careful in using models to avoid creating epistemological and ontological obstacles to the quantum view.

CONCLUSIONS

From the analysis of the categories that constitute the different zones of conceptual profiles of the atom and of the physical states of matter we can draw some conclusions about the relationship between different notions in a conceptual profile. Concerning the physical states of matter, the new atomistic concept can explain some features of the previous sensible and empirical concepts, without denying them. In this sense, a teaching process does not lead to a conceptual change, but to a change in the student's conceptual profile, increasing a rational profile zone and restricting the domains of others (the sensible-realist and empirical ones). The students who emerge from the teaching process would retain all the ideas that they had before. Nevertheless, I expect that those who have changed their profile and achieved consciousness of this process would be able to recognise different domains of each idea as well as their hierarchical framework, where some ideas explain others.

This change of conceptual profile is expected to happen with the theory of matter as well. The problem here is that one set of scientific ideas contradicts their alternatives, and the best way to overcome the contradiction is by eliminating one of the terms. Nevertheless, this calls for coherence is an epistemological feature of scientific and rational ideas, which is not necessarily found among the children's ideas or in common-sense reasoning. Even in Science it is possible to find apparently contradictory ideas co-existing in the same model or explanation, as, for example, the classical and quantum ideas in the Bohr's atom. When students acquire an atomistic way of seeing the world they can overcome the contradiction and give up the old ideas when dealing with problems in a scientific way. Even when this happens, it does not mean that the pupils abandon other parts of the conceptual profile. The continuous concept of matter continues to exist in the mind of the students, as in the mind of a physicist or a chemist. What happens is that pupils, just like the scientists, can acquire the capacity to discriminate as to when one or other concept is applicable. This means, to a certain extent, that students arrive at a consciousness of their own profile and can decide where each concept is applicable. For the students involved in learning elementary atomism, this profile realised after teaching only includes a few distinct zones, such as a realist view of matter (as something continuous) and a primary atomistic view (matter as constituted by particles in motion in empty space). In a scientist, as in physicist or chemist, the profile has other zones, such as a developed atomistic view (the atom as a system of sub particles) and a quantum view (the atom as a system of quantum objects described by mathematical models). Nevertheless, scientists as well as children that are conscious of their profile can use each notion at an appropriate moment.

It is possible to determine if a student has acquired a new zone in his/her conceptual profile by looking for the use of the categories that caracterise this zone in the explanation of some phenomena. Related to elementary atomism, this means that students are able to use categories such as discontinuity, motion-energy, interaction-arrangement in explaining transformations of matter as dilation, compression of gases, changes in the physical states and so forth. This kind of evaluation, however, can only show if students have a complete or incomplete grasp of the atomistic way of looking at the world. To verify if students use different stable elements of a conceptual profile in different occasions would require the use of a variety of problems according to each context identified in the theoretical analysis of the profile. The capacity to identify the context and to answer using the appropriate area of the profile could be an indication not only that a student has a profile but also that he or she is conscious of it. Obtaining this sort of data by means of individual interviews and tests will be important in order to verify the operationality of the notion of conceptual profile and to investigate how this profile can change as a consequence of teaching.

Empirical results as those from Galili and Bar (1992), showing that the same students who performed well in familiar tasks about force and motion reverted to pre-Newtonian reasoning of 'motion implies force' in non-familiar questions, are indicators that students have a profile of conceptions, as their previous beliefs were not replaced but coexist with the new view. Even a student that uses Newtonian reasoning in non-familiar questions would have this profile. The difference is that this student seems to be conscious of the best occasion to use each sector of the profile. He or she could apply the pre-Newtonian reasoning in an appropriate context, for instance, in everyday life. To talk about "the force of an argument" or of "the force of ultraviolet rays" (Collins Cobuild English Language Dictionary, 1987, p. 565) are examples of the appropriate use of a non-Newtonian conceptions of force in the everyday life. I believe that is possible to find similar results in other areas where the notions have a strong common-sense root. Scott (1987), for instance, investigating the development of a secondary pupil's ideas relating to matter, find that a student, at the end of the teaching, "was able to cleary differentiate between her 'life-world' and 'scientific' knowledge in stating that the former would be more useful in talking to her mother (who does not have a scientific background)" (Scott 1987, p. 417). The notion of conceptual profile provide a theoretical framework to interpret these kind of results. Moreover, the existence, in Science, of classical and modern views related to several concepts, as I have showed for the concept of the atom, is a strong indication that we cannot talk about a scientific view as opposed to a common-sense one, as this scientific view is not unique.

Using the notion of conceptual profile it is possible to deal with conceptual evolution in the classroom not as a conceptual change, but as a change, accompanied by the acquisition of consciousness, of the student's conceptual profile. I have used this idea to inform and analyse the teaching of the theory of matter in secondary schools. It has directed the choice of teaching strategies to deal with obstacles to the construction of an elementary scientific viewpoint. It has also been used to evaluate the conceptual evolution, by selecting different categories within a hierarchy that allow tracing the direction of this evolution. I believe that it is possible to use this theoretical framework to analyse the teaching process for this and for other concepts, which could generate future research. An important question to be addressed in this research is how to determine the profile of each individual before and after teaching and to what extent he or she achieves a consciousness of this profile at the end of the teaching process.

ACKNOWLEDGMENTS

This work was supported by grants from CNPq, CAPES (PADCT-SPEC) and Pró-Reitoria de Pesquisa da UFMG. An academic visit to CLIS (Children's Learning in Science Research Group, University of Leeds, UK) made it possible to write this article. I am very grateful to Rosalind Driver, Phil Scott and three anonymous reviewers for their suggestions in early versions of this article.

REFEREMCES

Bachelard, G.: 1968, *The philosophy of No*, The Orion Press, New York. Translated from *La philosophie du non*, 1940, by G.C. Waterston.

Berger, P.L. & Luckmann, T.: 1967, *The Social Construction of Reality: A Treatise in the Sociology of Knowledge*, Allen Lane, London.

Bohr, N.: 1935, 'Can Quantum-Mechanical Description of Physical Reality be Considered Complete?', *Physical Review* **48**, 696–702.

Chi, M.T.H.: 1991, 'Conceptual change within and across ontological categories: Examples from learning and discovery in science', in R. Giere (ed.), *Cognitive models of Science: Minnesota Studies in the philosophy of Science*, University of Minnesota Press, Minnesota.

Claparède, E.: 1946, *L'education fonctionnelle*, Delachaux et Niestle, Neuchatel.

Driver, R.: 1989, 'Students' conceptions and the learning of science', *International Journal of Science Education* **11**(5), 481–490.

Durkheim, E.: 1972, *Selected Writings*, Cambridge University Press, Cambridge (original work published in 1895).

Einstein, A., Podolsky, B. & Rosen, N.: 1935, 'Can Quantum-Mechanical Description of Physical Reality be Considered Complete?', *Physical Review*, **47**, 777–780.

Faraday, M.: 1844, 'A speculation touching Electric Conduction and the Nature of Matter', *Phil. Mag.*, **24**, 136–144. Reprinted in Knight, D.M. (ed.), 1968, *Classical Scientific Papers – Chemistry*, Mills & Boon, London.

Galili, I. & Bar, V.: 1992, 'Motion implies force: where to expect vestiges of the misconceptions?', *International Journal of Science Education*, **14**(1), 63–81.

Hewson, P.W. & Thorley, R.: 1989, 'The conditions of conceptual change in the classroom', *International Journal of Science Education*, **11**(5), 541–553.

Linder, C.J.: 1993, 'A challenge to Conceptual Change', *Science Education*, **77**(3), 293–300.

Kozulin, A.: 1990, *Vygotsky's Psychology: A biography of ideas*, Harvester Wheatsheaf, New York.

Marton, F.: 1981, 'Phenomenography – Describing conceptions of the world around us', *Instructional Science*, **10**, 177–200.

Matthews, M.R.: 1992, 'Constructivism and empiricism: an incomplete divorce', *Review of Educational Research*, **22**, 299–307.

McDermott, L.C.: 1984, 'Research on conceptual understanding in mechanics', *Physics Today*, July 1984.

Niedderer, H., Goldberg, F. & Duit, R.: 1991, 'Towards Learning Process Studies: A review of the Workshop on Research in Physics Learning', in R. Duit, F. Goldberg and H. Niedderer (eds.), *Research in Physics Learning: Theoretical Issues and Empirical Studies*, IPN, Kiel, 1991, 10–28.

Piaget, J.: 1977, *The development of thought: Equilibration of Cognitive Structures*, Basil Blackwell, Oxford. Translated from *L' Equilibration des structures cognitives*, 1975, by Arnold Rosin.

Popper, K.R.: 1972, *Objective Knowledge: An evolutionary approach*, Oxford University Press, Oxford.

Posner, G.J., Strike, K.A., Hewson, P.W. & Gertzog, W.A.: 1982, 'Accommodation of a scientific conception: Toward a theory of conceptual change', *Science Education*, **66**(2), 211–227.

Séré, M.G.: 1986, 'Children's conceptions of the gaseous state, prior to teaching', *European Journal of Science Education*, **8**(4), 413–425.

Solomon, J.: 1983, 'Learning about energy: how pupils think in two domains', *European Journal of Science Education*, **5**(1), 49–59.

Schutz, A.: 1967, *The phenomenology of the social world*, Northwestern University Press, New York. Translated from *Der Sinnhafte Aufbau der Sozialen Welt*, 1932, by G. Walsh and F. Lehnert.

Scott, P.: 1987, 'The process of conceptual change in Science: A case study of the development of a secondary pupil's ideas relating to matter', in Novak, J.D. (ed.), *The proceedings of The Second International Seminar: Misconceptions and Educational Strategies in Science and Mathematics*, Cornell University, Ithaca, vol. II, 404–419.

Stavy, R. & Stachel, D.: 1985, 'Children's Ideas about "solid" and "liquid"', *European Journal of Science Education*, **7**(4), 407–421.

Stavy, R.: 1988, 'Children's conceptions of gas', *International Journal of Science Education*, **10**(5), 530–560.

Stavy, R.: 1990, 'Children's conceptions of changes in the state of matter: from liquid (or solid) to gas', *Journal of Research in Science Teaching*, **27**(3), 247–266.

Toulmin, S.: 1961, *Foresight and Understanding: An enquiry into the aims of science*, Hutchinson, London.

Van Melsen, A.G.: 1952, *From atomos to atom: The History of the Concept Atom*, Duquesne University Press, Pittsburgh.

Vygotsky, L.S.: 1962, *Thought and Language*, MIT Press, Cambridge. Translated from *Myshlenie i rech*, 1934, by E. Hanfmann and G. Vakar.

Vygotsky, L.S.: 1978, *Mind in Society: The development of higher psychological process* (M. Cole, V. John-Steiner, S. Scriner & E. Souberman, eds.), Cambridge University Press, Cambridge.

Vygotsky, L.S.: 1982, *Sobranie Sochinenni* (*Collected Papers*), vol. I, Pedagogika, Moscow (original work published in 1926), cited by Kozulin, 1990.