Third Misconceptions Seminar Proceedings (1993)

Paper Title: **STUDYING CONCEPTUAL EVOLUTION IN THE CLASSROOM AS CONCEPTUAL PROFILE CHANGE**

Author: MORTIMER, EDUARDO FLEURY

Abstract: 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.

Keywords: Concept Formation,Educational Methods,Theories,Concept Formation,Concept Teaching,Epistemology,Learning Strategies,Atomic Theory,Learning Process
General School Subject: Science
Specific School Subject: Chemistry
Students: Secondary School

Macintosh File Name: Mortimer - Conceptual Profile
Release Date: 12-16-1993 C, 11-6-1994 I

Publisher: Misconceptions Trust
Publisher Location: Ithaca, NY
Volume Name: The Proceedings of the Third International Seminar on Misconceptions and Educational Strategies in Science and Mathematics
Publication Year: 1993
Conference Date: August 1-4, 1993
Contact Information (correct as of 12-23-2010):
Web: www.mlrg.org
Email: info@mlrg.org

A Correct Reference Format: Author, Paper Title in The Proceedings of the Third International Seminar on Misconceptions and Educational Strategies in Science and Mathematics, Misconceptions Trust: Ithaca, NY (1993).

this paper on to a colleague, please make sure you pass it on intact. A great deal of effort has been invested in bringing you this proceedings, on the part of the many authors and conference organizers. The original publication of this proceedings was supported by a grant from the National Science Foundation, and the transformation of this collection into a modern format was supported by the Golton/Novak Fund, which is administered by the Department of Education at Cornell University. If you have found this collection to be of value in your work, consider supporting our ability to support you by purchasing a subscription to the collection or joining the Meaningful Learning Research Group.

----- -----

STUDYING CONCEPTUAL EVOLUTION IN THE CLASSROOM AS CONCEPTUAL PROFILE CHANGE

EDUARDO FLEURY MORTIMER

FACULDADE DE EDUCAÇÃO DA UFMG
Av. ANTÔNIO CARLOS 6.627
31.270-901 - BELO HORIZONTE - MG - BRAZIL
and
CHILDREN'S LEARNING IN SCIENCE RESEARCH GROUP (CLIS)
UNIVERSITY OF LEEDS
LEEDS, LS2 9JT. ENGLAND, UK.

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 and Gertzog, 1982, p. 211), 'conceptual change' became a synonym for 'learning science' (Niedderer et al, 1991), which does not means 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. 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 and 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 and evaluate a strategy to teach the theory of matter.

THE CONCEPTUAL PROFILE NOTION

That people can have different ways of seeing and representing their world is not a new idea. Bachelard had already introduced it in 1940, related to what he had called 'the notion of an epistemological profile' (Bachelard, 1968). 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).

Bachelard is not alone in considering that there are different ways of seeing the world that can be found in the same person. Popper, for instance, talks about 'the third world', as "*knowledge or thought in an objective sense,* consisting of problems, theories, and arguments (...and) totally independent of anybody's claim to know, (...) independent of anybody's belief, or disposition to assent" (Popper, 1972, p. 108-109). Besides this 'third world' there is the 'second world' of "*knowledge or thought in the subjective sense*, consisting of a state of mind or of consciousness or a disposition to behave or to react" (Popper, 1972, p. 108), and the 'first world' of physical objects or of physical states. Despite enumerating just three ways, Popper agrees that we might express our worlds in several different ways: "We might, especially, distinguish more than three worlds. My term 'the third world' is merely a matter of convenience" (Popper, 1972, p. 107).

Other arguments in favour of the existence of "qualitatively different ways in which people perceive and understand their reality" were brought up by Marton (1981, p. 177), whose 'phenomenographical' approach talks about conceptions and ways of understanding not as individual qualities but rather as 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). As in Popper, 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.

Nevertheless, it is in Bachelard's 'The Philosophy of No' (1968) that we find a more detailed explanation of different ways of conceptualising reality in terms of scientific concepts. I think it would help us to developed a model of teaching that makes children's ideas explicit but at the same time tries to solve some of the inconsistencies raised above.

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 have, as in Marton, a more general characteristic. Each area of the profile is related to a specific philosophical perspective, based on specific epistemological commitments.

Bachelard illustrated his notion with the concept of mass. The earliest form of the concept 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. Sere, 1986; Stavy 1988 and 1990).

The second level of the profile 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 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, 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 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 profile is weaker than mine, probably because he hardly uses scales in his work routine. In compensation, he has a stronger rational sector, related to his experience of teaching Newton's laws. The modern sector of his profile is also stronger than mine because he 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

FIGURE 1
MY EPISTEMOLOGICAL PROFILE OF MASS CONCEPT

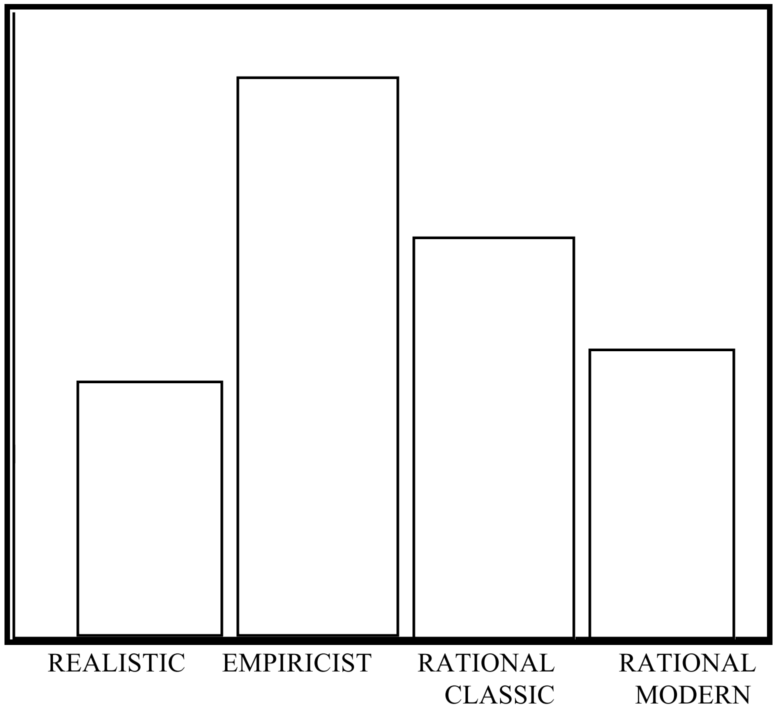
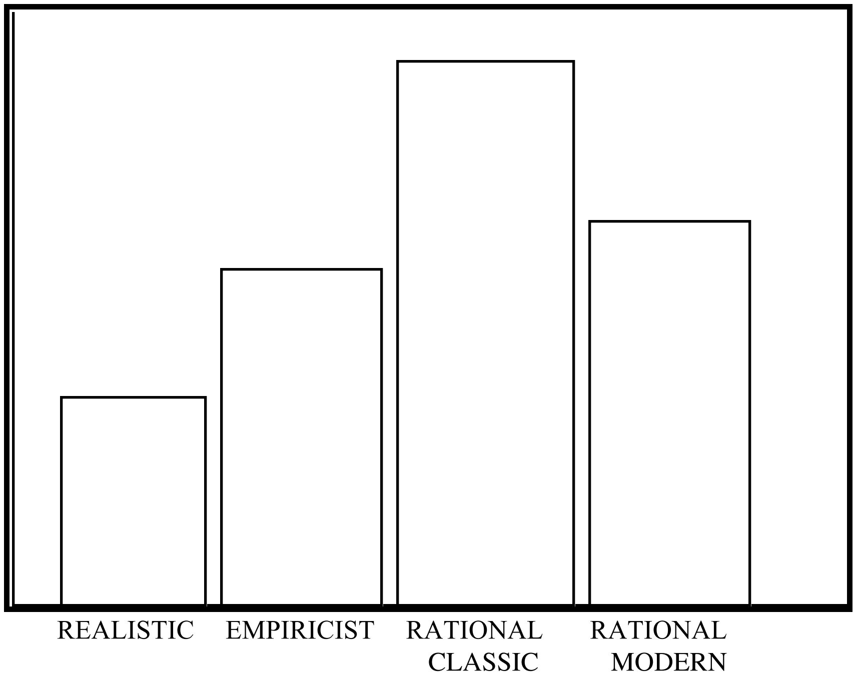


FIGURE 2
A PHYSICIST'S EPISTEMOLOGICAL PROFILE OF MASS CONCEPT



eyes. I would agree, since somebody could prove that a chemist or a physicist had never used mass in a metaphorical sense in his everyday language, he had never spoken about a 'mass of papers in his briefcase' or a 'mass of detail to be worked out'. In these senses, mass is clearly realistic and it would be nonsense to speak about a *small mass* of detail 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.

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. "In order for students to really understand what forces, light, heat, and current are, they need to change their conception that these entities are substances, and conceive of them as a kind of constraint-based event (including fields), thereby, requiring a change in ontology." (Chi, 1991, p. 13).

Another important feature of my 'conceptual profile' is that its 'pre-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, we 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 our 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'. 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 identified 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. 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. 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 epistemological and ontological obstacles as well as of trying to minimise and lower them, to help overcome them. In this way, he performs a set of different functions: to make the agenda explicit; to address the epistemological and ontological obstacles and the epistemological features of the scientific knowledge to be learned; to reduce the degrees of freedom that the pupil has to manage in the task of recognising and overcoming the obstacles that are interposed between his 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 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 thoughts and never more remain submerged in his mental functions. Once he acquires this ability, he can perform this analysis and use criteria like coherence, logical consistency and accordance with experience. Besides this, he is more flexible and open to other ideas, and can compare them with his own ideas, criticise and overcome his 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 for use as a tool in criticising the lower level of the same concept and 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 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 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 his 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 and 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 our world. 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. This is an unreal and pointless expectation. Everyday language 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, has a rich history of successive models increasingly suitable for experiments, and because it is also possible to discern a profile of alternative 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 alternative ideas about matter in check. On the contrary, these alternative ideas seem to be coherent, plausible and fruitful, 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 literature and 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, they wet and have water', are very useful 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 a negation as well, 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 and Stachel, 1985; Stavy, 1988).

The second zone of the profile I call substancialist atomism. Substancialism 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. Nevertheless, 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 debate 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? (Amaral, 1991).

There is no concept of the physical states of matter that corresponds to this substancialist 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 concepts, 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 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 substancialism 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 'substancialist 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; substancialism/non-substancialism; 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 kinetic energies and different interactions between particles in each state. It follows that solids are arranged in a very orderly fashion because of the low kinetic energy and 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 because of their higher kinetic energy. In the gaseous phase, particles have a still higher kinetic energy and 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, for examples, 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 'substancialist' 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.

It may be that I am not 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, which ..... 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 interpretation of 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 and Rosen, 1935 and 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.

ANALYSING CONCEPTUAL EVOLUTION IN THE CLASSROOM USING THE CATEGORIES OF THE CONCEPTUAL PROFILE OF THE ATOM AND OF THE PHYSICAL STATES OF MATTER

I shall analyse the results of a pre- and post-test of one class in order to explain how to detect a change in students' conceptual profiles. I think this is an important task because we have to be able to detect the conceptual evolution that we imagine may happen in a class using categories to analyse the students' conceptions before and after teaching. The categories to be used were defined previously from the atom and from the physical states of matter conceptual profiles.

The class analysed corresponds to the Brazilian year eight (age 14-15), when for the first time the atomic model of matter is taught. We apply a pre-test at the beginning of the 12 lessons (50 minutes each) and a post-test at the end. The analysis of the results of pre- and post-test will show the conceptual evolution of the students and I shall try to describe this evolution as a change in their conceptual profile.

STUDENTS' CONCEPTIONS OF MATTER BEFORE TEACHING

All the problems proposed in the pre-test involved a phenomenon in which matter was in a process of transformation that could be somehow reproduced by the student himself or experienced in his everyday life. Four problems related to gases were selected: air compression in a syringe with the end sealed; dilation of air submitted to heating in a test tube with a balloon over its neck; vacuum in a flask connected to a large syringe; and gas odour spreading throughout a kitchen as it expands into space. There were two other problems related to liquids and solids: dilation by means of heating the alcohol column of a thermometer by hand; and melting and vaporisation of a naphthalene ball heated in a test tube.

These phenomena were selected because they allowed for an explanation using some of the features of the atomistic model we were investigating. Of fundamental importance in this regard was the use of transformations since we had already asked for a definition for solids, liquids and gases - not involved in transformations - which, in their turn, had demonstrated the use of atomistic features only by 3 students. If the students were asked to draw and explain models for a system before and after any sort of transformation it might prompt them to use an internal entity related to the system that was conserved during the transformation: the atoms.

The students were asked both to describe their observations about each phenomenon and to draw a model for the material before and after the transformation. They were also asked to explain their models. Whenever possible we asked questions about the mass and density of the system before and after the transformation. Moreover, an analysis of the atomic conceptual profile suggests that it would be far more convenient to ask students to represent models rather than draw what they imagine might be happening 'inside the material', or to draw the material as if it were seen through very powerful magnifying glasses. These last questions might lead students to a realistic answer since the behaviour suggested (seeing) would not be adequate for dealing with constructed models. If we are concerned with leading students to construct a new zone of the profile, different from the realistic one, we must be careful to avoid reinforcing realistic features. The realistic view implicit in tasks such as 'drawing the material as if it were seen through very powerful magnifying glasses' could prompt youngsters to reason without using the features of an intuitive atomistic model.

We decided to consider as an evidence of the use of mass conservation the answers in which students had said that the mass of the system before (m_1) a transformation such air compression was equal to the mass of the system after (m_2) the transformation. In general, students who gave other answers ($m_1 < m_2$ or $m_1 > m_2$) had confused mass with density or with volume, using expressions such as: "mass is smaller because it fills up a smaller space"; or "the material is more compact in 1". Yet, the students who explicitly made use of substancialist ideas tended to explain the non-conservation of mass through the change ascribed to particles claimed, for example, that "heat makes particles lighter".

Table 1 reveals the positive aspects of the categories I defined previously, used by each student. Positive aspects are defined here as the characteristics that are similar or near to those of the atomistic model which Science accepts. The answers taken as such are those in which students referred to any atomistic aspect in their definition of solid, liquid and gas; represented matter in a discontinuous and non-substancialist way; and showed evidence of the use of mass conservation.

As to mixed responses, such as those involving the continuous model for some phenomena and the discontinuous model for others, we decided to select the answer students used for at least two different physical states. That is to say, a student who used the discontinuous model for the four phenomena involving gases but not for ones involving liquids and solids was classified as continuous, whereas a youngster using the discontinuous model for the phenomena involving gases and for the liquid dilation was classified as discontinuous. The same criterion was used for substancialism and conservation of mass. However, concerning the mixed answers for the definition of solids, liquids and gases we decide on the atomistic definition as the one that should prevail because it denotes a construction that is based upon the intrinsic features of objects and not their external aspects.

The data vertically displayed in Table 1 clearly shows the existence of four kinds of conceptual framework related to the given phenomena. The first group is composed of pupils who conceptualise solids, liquids and gases in a sensible and empirical way, who have a continuous conception of matter and do not conserve mass in the majority of the transformations. Most obviously, the absence of substancialism in this group is not surprising as it presupposes the existence of a discontinuous view of matter, which would allow for macroscopic properties to be attributed to sub-microscopic particles. Gla, Rod, Den and Eli are the students included in this group.

The second group includes youngsters whose definition of solids, liquids and gases was sensible and empirical. As in the first group, the pupils show a continuous conception of matter, but they conserve mass in most of the transformations in the given phenomena. The latter feature markedly distinguishes this group from the first one. This feature is relevant in that it shows the independence of conservation reasoning in relation to atomism. These pupils who realised the mass conservation did not use atomistic reasoning, but the logic of 'nothing gets in, nothing gets out'.

Raq, Lin and Edw belong to this group. In spite of having made references to the atomistic features in his definitions for solids, liquids and gases, Edw made no use of the

Table1
Youngsters' conceptions that are close to an atomistic view of matter

Student (age)	Atomistic definition of solid, liquid, gas	Descontin. representat. of matter	Absence of substancia-lism	Evidence of conservation of mass
Gla (15)			? ?	
Rod (14)			??	
Den (14)			??	
Eli (15 - rep)			??	
Igo (15)	_________ _	_________ _		
Raq (15)			??	_________ _
Lin (15)			??	_________ _
Edw(18 - rep)	- _________ _		??	_________ _
Eri (15)		_________ _	- ________ __	
Car (16)		_________ _		_________ _
Gus (15)		_________ _		_________ _
Ale (15 - rep)		_________ _		_________ _
Fab (14)		_________ _		_________ _
Lil (14)	no result	_________ _		_________ _
Ref (14)		_________ _		_________ _
Rog (16-rep)	_________ _	_________ _	________ __	
Bia (15)		_________ _	________ __	_________ _
She (16 - rep)		_________ _	________ __	_________ _

Elv (15 - rep)	no result	_________ _	________ __	_________ _
Cao (15)		_________ _	________ __	_________ _
Dan (14)		_________ _	________ __	_________ _
Jan (14)		_________ _	________ __	_________ _

Legend:

__________ indicates the presence of the category at the head of the column in the student's concept of matter

rep indicates the student that is attending the same year again

?? indicates that the substancialist category does not demonstrate anything concerning these students, as they did not use a discontinuous representation of matter discontinuous representation of these given phenomena. This procedure, in fact, demonstrates that he failed to construct an atomistic concept since he does not use it to explain phenomena, but only for their definition. Thus, I decided to classify Edw in this group.

The third group comprises youngsters whose definition of solids, liquids and gases was sensible and empirical. As in the second group the pupils conserve mass in most of the transformations but on the other hand they show a discontinuous conception of matter. Nevertheless, this discontinuous view of matter is substancialist too. Discontinuity distinguishes this group from the second one whereas substancialism distinguishes it from the fourth. Car, Gus, Ale, Fab, Lil and Ref belong to this group.

These first three groups, from our standpoint, share a view that is far from being consonant with a scientific atomistic concept. I conclude that their conceptual profile of matter includes only the realistic and the empirical zones, without any rational atomistic component.

The fourth group is composed of youngsters who, in spite of having given a sensible and empirical definition of solids, liquids and gases, made use of a discontinuous and non-substancialist representation for the materials, besides having conserved mass in most of the transformations. These students' conceptions may be considered as close to scientific atomicism. They, undoubtedly, failed in providing references to the interaction between particles, to their arrangement or to their motion and energy. There seems to be, however, no major obstacles for the teaching of these ideas. Maybe the only obstacle would that of reasoning about the existence of a vacuum that no student referred to explicitly. Bia, She, Elv. Cao, Dan. Jan and Res belong to this group.

Three students presented a different result that does not allow us, immediately, to list them in one of the four previous groups. We could include them in a separate group as they shared two striking features: they made use of discontinuous representations and did not conserve mass. As for the other characteristics, only one of the students was substancialist and two of them used atomistic definitions for solids, liquids and gases. Because this group did not conserve mass, though they did use atomism, the view that there is a certain independence between the mass conservation and the use of atomistic reasoning is reinforced.

It would appear that this group occupies an intermediate position between the first three groups and the fourth one. The absence of conservation is a feature of both groups 1 and 2, whereas the discontinuous view of matter without substancialism characterises group 4. Igo is most likely to belong to groups 1 and 2 because he has a substancialist view and does not conserve mass. Eri and Rog, in turn, do not conserve mass and do not use a substancialist view, and this makes them similar to group 4. Based on such features and because we wished to preserve the clear characteristics presented in the other groups, we placed Igo in an intermediate position between groups 1 and 2, and included Eri and Rog between groups 3 and 4.

The results obtained are identical to those available in the relevant literature (see, for example, Piaget and Inhelder, 1941; Doran, 1972; Novick and Nussbaum, 1978; Driver, 1985; Griffiths and Preston, 1992). Like children throughout the world, some of our pupils showed difficulty in understanding mass conservation and some of them do not use a discontinuous model to represent matter. Among those who used such models some used substancialist ideas as well. Moreover, our youngsters who used atomistic ideas did not make use of other aspects of the scientific model in their explanations such as the intrinsic motion of particles and their arrangements.

STUDENTS' CONCEPTUAL PROFILE AFTER TEACHING

The results our pupils showed after formal instruction are not to be analysed only with the same categories used for the pre-test. Before such an instruction even those pupils who made use of a model very close to scientific atomism tend to fail to realise all the concepts. If the main purpose of formal instruction is to help construct the scientific atomistic model, it is expected that instruction advances a pupil's meaningful understanding of all of those concepts. The categories of analysis will have to be based on the intrinsic features of the model which pupils must be capable of using in different situations. Beyond this, it is important to verify the stability of the new ideas.

Students may grasp some features of classical atomism but these new ideas may be undifferentiated from some of their previous conceptions. In other words, they may not achieve consciousness of their own conceptual profile. To check this possibility, I selected two other categories: the first one aims to verify if the students generalise (or not) the new concepts in new phenomena; the second, if the students recognise as such a potentially disturbing phenomenon, and, once recognised, they compensate for the disturbance. In the end, we will have to verify if the students perceive (or not) a relationship between the different concepts of states of matter, and recognise the boundary of each one.

By testing the stability of the new ideas I expect to be able to detect if students achieve consciousness of their profile (or not). This is not an easy task and we can not ensure that a student who compensates for a specific disturbance will compensate for any other. We can be certain only of the negative cases but not of the positive ones. If students do not recognise the disturbance or; even if they recognise, but try to compensate for it using conceptions belonging to the first two zones of the atomic concept's profile (realistic and substancialist) instead of classical atomism I would conclude that they are not able to recognise the boundaries of each zone of their profile, i.e., they do not achieve consciousness of their profile. The alternative is not always true, since it depends on the nature and extent of the disturbance. Nevertheless, I would consider the compensation of a disturbance as strong evidence that students achieve consciousness of their own profile.

However, the persistence of alternative conceptions is also to be expected. Because of that we shall analyse post-test data in the light of categories such as substancialism/non-substancialism, conservation/non-conservation of mass, continuity/discontinuity, as well. The latter category will be analysed together with other inherent features of the model such as intrinsic motion associated with kinetic energy; and the arrangement associated with different kinetic energies and different interactions between particles in each state.

The post-test was devised with the aim of observing the above-mentioned features. In most of the tasks students were asked to draw models for the materials before and after the transformations. Then we asked them about both mass and density variations of the material. This means that the post-test was designed with the same structure as the pre-test in spite of not setting similar questions, thus allowing for a comparison of results.

The first problem presented in the post-test had the same system as the pre-test: compression of air in a syringe with the end sealed. The second had a system very similar to the one used for dilatation during the pre-test but not identical with it: the heating of an elastic balloon resistant to fire and containing helium. The third task was different from the one used in the pre-test and had not been taught previously: an iron bar (solid) was heated slowly. These three tasks aimed at evaluating the intrinsic features of the atomistic model (discontinuity, motion and arrangement) in the youngsters' drawings and explanations. The third task also aimed at evaluating the students' capacity for generalising these features, using them in a new situation, such as the dilation of a solid. This is not so obvious as that of a liquid in a column, or a gas in an elastic container.

The fourth problem was about the three physical states of water, which behaves in a particular way, that is, the density of the solid state is less than that of the liquid. The task reminded the students that ice floated on liquid water, which was considered to be sufficient information for the pupils who had already been taught about density and who had demonstrated a good grasp of the concept in the pre-test. Such questions aimed at evaluating not only the presence of the features of the atomistic model but also the youngsters' capacity for recognising and compensating for a potentially problematical phenomenon. The fact that ice density is less than liquid is a potential disturbance. Thus, pupils capable of recognising such a disturbance and changing the features of their model based on such a contradictory fact would reveal a fair level of generalisation of these features to new situations and of compensation in potential situations of conflict.

That problem was chosen because it is a recognisable disturbance. The results of a piece of research with 227 Portuguese pupils aged between 13 and 18 years, revealed that none of them had taken the fact that was mentioned into account when proposing models for water in solid and liquid states(Pereiraand Pestana,1991). Moreover, the results of another investigation, in which a very similar type of question was put to students who had completed their second grade courses (age 17-18) in Belo Horizonte and other cities of Minas Gerais State, Brazil, reinforced our view about the difficulties of remedying such difficulties (Mortimer, 1990). On analysing the answers we found only 13.0 per cent of the students who had taken the density datum into account, as they drew it in their models either by depicting hollow spaces on the ice structure (0.6 per cent) or by maintaining distances between molecules in the ice larger than those in the liquid water (12.4 per cent). The percentage of pupils who maintained ice molecules in an ordered arrangement, in spite of the larger distance, was smaller: 5.6 %. These results were obtained from a random sample of 20 per cent (602 students out of 2,985) of the pupils trying to take courses in Engineering (mechanical, civil, electrical, chemical, metallurgic and mining), Geology, Physics, Chemistry, Medicine, Veterinary Surgery, Dentistry, Biology, Pharmacy, Physiotherapy and Nursing.

As our students had just been introduced to the atomistic model, they were not able to give a complete answer to the problem (the hollow spaces in the ice structure due to the increase in the number of hydrogen bonds in the solid state) as they did not have sufficient knowledge to do so. What we could, in fact, evaluate by way of compensation was the possibility of students changing the relative distance of solid and liquid particles according to the datum about density. For our students to follow such a line of thought they had to consider the relations: flotation-density, density-volume and volume-distance between particles.

Continuing with the post-test, we shall now examine the fifth question. It was a phenomenon in which naphthalene was dissolved in carbon tetrachloride, and the pupils were asked to explain the process and to answer why naphthalene dissolves in carbon tetrachloride and does not dissolve in water. The process of dissolving had been already explored through spontaneous dissolving of potassium manganate (VII) in a given mass of water (without shaking the solution) and of salt and sugar in water forming colourless solutions. Although the difference in solubility in different solvents had not yet been investigated we expected the pupils would generalise the model that stated that dissolving implies the existence of interaction between particles of the solute and the solvent, which would explain why naphthalene is not soluble in water. This question was, in some aspects, similar to others already dealt with previously; but this one demanded a certain level of generalisation and of compensation, related to differences in solubility of naphthalene in water and carbon tetrachloride. Nevertheless, it was expected that this situation would be more easily compensated for than that of water and ice, since it would not involve the reformulating of the features in the solubility model that had already been taught, but would only imply its generalisation to a phenomenon in which solubility does not occur.

The purpose of the sixth and last question was to examine to what extent the pupils link their previous sensible and empirical concepts about gases, liquids and solids, with the atomistic ones. The first item dealt with the question: Why should clouds and fog not be classified as gases if they had changeable shape and volume? The second one was meant to discuss the physical state of glass starting from the idea that its particles are in non-ordered arrangement. These two items had already been discussed during the lessons. In the third item pupils were asked to discuss the physical state of a substance that possesses liquid properties, like those that assume the shape of a container, but whose particles are oriented (like those in a liquid crystal). This item had not yet been discussed in the classroom.

The post-test was given after the instruction process had finished. The evaluation of the results was rigorous and markedly different from that of the pre-tests, in which our conclusions were predominantly based on the analysis of the drawings because students' responses were insufficient. In the post-test, however, we based our conclusions not only on pupils' drawings but also on their reasoning, since they had already been exposed to formal teaching whose aim was to help pupils construct the knowledge we were trying to evaluate.

PUPILS' ATOMISTIC IDEAS AFTER TEACHING

We shall now try to correlate the results obtained. Overall, our aim is to detect alterations in pupils' atomistic ideas as a result of the instruction process. Thus, we shall list them in table 2 and evaluate whether students:

1. used the features of the atomistic model, such as discontinuity, intrinsic motion and arrangement, to explain the transformations;
2. conserved mass in these transformations;
3. generalised their ideas in the face of a new situation;
4. compensated for the given disturbance and
5. associated the empirical and atomistic concepts of the physical states.

If students only partly present these features this will be indicated by partially filling the corresponding column. The number of marks (—) is proportional to the use students made of the conceptions in each case. We have a maximum of 5 marks related to the use of features of the atomistic models, as we have 5 different phenomena in which students were asked to explain the transformations using those features. We have to bear in mind that each transformation does not necessarily need to be explained by all the features. A phenomenon such as air compression on an end sealed syringe, for example, does not have to be explained in terms of the motion of gas particles, but in terms of the existence of empty space between the particles. However, reference to intrinsic particle motion is fundamental to explain the dilation of gases, liquids and solids.

We have the same maximum number of marks for evidence of use of mass conservation, as this feature could be verified in all the 5 transformations. We have a maximum of 2 marks for generalisation, since we only have two phenomena in which students had to generalise the model's features with regard to a new situation (solid dilation and difference in solubility). As the relationship between different conceptions of physical states of matter was verified in three materials, we have a maximum of 3 marks for this situation.

Finally, I chose to use letters to describe the compensation for a disturbance as this feature was only verified in the physical state of water. A blank space means that the students did

Table 2
Students' atomistic view after instruction

Student (age)	Features of the atomistic model (5 phenomena)	Evidence of Conservation of mass (5 phenomena)	Capacity to generalise (2 phenom)	Relation between concepts of physical states (3 phenomena)	Compensat. for a disturbance (1pheno men.)
Lin (15)	—	— — — — —		—	
Rod (15)	— —	— — —			
Res (14)	— — —	— — — — —		—	
Eli (15-r)	— — —	— — — — —	———		r r r
Edw (18-re)	— — — —	— — — — —	———	—	
Gla (15)	— — —	— — — — —	— — — — — —	— — —	
Raq (15)	— — — — —	— — — — —		— — —	r r r
Eri (15)	— — — — —	— — — — —		— — —	r r r
Ale (15-re)	— — — — —	— — — —	— — — — — —	— — —	
Bia (15)	— — — — —	— — — — —	— — — — — —	— — —	
Fab (14)	— — — — —	— — — — —	— — — — — —	— — —	
Igo (15)	— — — — —	— — — — —	———	— — —	r r r
Lil (14)	— — — — —	— — — — —	— — — — — —	— — —	r r r
She (16-re)	— — — —	— — — —	———	— —	rrr sss
Rog (16-re)	— — — —	— — — —	— — — — — —	— — —	rrr sss
Den (14)	— — — — —	— — — — —	———	— —	rrr ppp
Car (16)	— — — — —	— — — — —	— — — — — —	— — —	rrr ppp

Cao (15)	—— —— —— —— ——	—— —— —— —— ——	– – – – – –	– – – – – –	rrr ppp
Dan (14)	—— —— —— —— ——	—— —— —— —— ——	———	—— ——	rrr cccc ttttt
Jan (14)	—— —— —— —— ——	—— —— —— —— ——	– – – – – –	—— ——	rrr cccc ttttt
Elv (15-re)	—— —— —— —— ——	—— —— —— —— ——	– – – – – –	—— ——	rrr cccc ttttt
Gus (15)	—— —— —— —— ——	—— —— —— —— ——	– – – – – –	– – – – – –	rrr cccc ttttt
Ref (14)	—— —— —— —— ——	—— —— —— —— ——	– – – – – –	– – – – – –	rrr cccc ttttt

Legend:

—— indicates the use, by the student, of the category at the head of the column in 1 phenomenon.

re - indicates a student who is repeating a year.

In the Compensation for a disturbance column:

blank - the student ignores the disturbance.

rrr - the student recognises the disturbance but does not change anything in his/her drawing or explanations.

rr sss - the student recognises the disturbance and changes his/her drawing and explanations, but in a substancialist way.

rr ppp - the student recognises the disturbance but changes only his/her explanation (partial compensation).

rr cccc ttttt - the student recognises the disturbance and changes both his/her drawing and explanations (total compensation).

not recognise the disturbance and affirmed that the models of the three physical states of water were the same as any other material. The letters 'rrr' means that students recognised the disturbance by affirming that the model of water in a solid state could be different from other materials, but did not change anything in their drawing or explanation. The letters 'rrr ppp' means that students recognised the disturbance but only changed their explanation and not their drawing. If the students also changed their drawing, but in a substancialist way (increasing the size of ice particles instead of the spaces between them), I use the letters 'rrr sss' to indicate the use of such a substancialist compensation. Finally, 'rrr cccc ttttt' means that students recognised and compensated completely for the disturbance, drawing the ice particles wider apart than the liquid water particles and explaining their drawing adequately.

As I had already done with the pre-test results, I decided to list pupils according to the features they had in common. In a search of these common features we can recognise 3 different groups of student answers.

The first group is composed of students who showed a gap in their atomism, had little or no capacity for generalising when using the features of that model, set little or no relation between the conceptions of physical state and did not compensate for the given conflict. Despite all this, the majority conserved mass in the transformations. Included in this group are Lin, Rod, Fre, Res and Eli. Four of these pupils retained some traces of their substancialist and continuous beliefs (Lin, Rod, Res and Eli).

The second group is made up of students who used all the features of the atomistic model in the various transformations. They conserved mass during the transformation and in almost all cases specified set relations between the concepts of the physical states. However, they had some difficulties in compensating for the disturbance and in generalising the use of the model in all the new situations. Ale, Bia, Raq and Eri are included in this group. We also placed Gla and Edw in an intermediate position, between groups I and II because they did not use all the features of the model.

The third group is formed of students who used all the features of the atomistic model, conserved mass in all the transformations, related the different concepts of physical states of matter and demonstrated a capacity for fully or almost fully generalising and compensating for a disturbance. Den, Car, Cao, Dan, Jan, Elv, Gus and Ref are part of this group. Fab, Igo and Lil were placed in an intermediate position between groups II and III because Fab and Lil generalised completely but only showed a rudimentary compensation, whereas Igo besides not generalising completely presents a very rudimentary compensation.

Rog and She were placed in group II for practical purposes, but in fact they constitute a separate group as they showed very distinctive features. Both did not use all the characteristics of the model in the transformation. Nevertheless, they demonstrated a capacity for generalising and should be classified under the category of complete compensation because they changed their models when confronted with a disturbance. Such change, however, was a substancialist one and both changed the particles size to compensate for the disturbance instead of changing the distance between them. Is interesting to note that Rog seemed to be give up his substancialist ideas, which did not appear in other transformations. However, in a situation of conflict and difficulty, the idea reappeared. This demonstrates not only the difficulty of dealing with new ideas in conflict or problematic situations, where the old ideas tend to reappear, but also the validity of the 'stability of a new idea' as a category for analysing the problem of conceptual evolution.

CHANGES IN THE CONCEPTUAL PROFILE

We shall now compare the overall result with that obtained in the pre-test. At that time, I also classified pupils but into four groups. Pupils and the position they were placed in the pre-test as well as those into which they are now inserted, are displayed in table 3. Below it we listed the main features of each group. We decided to use roman numerals for the post-test groups so as to avoid confusion with the pre-test groups.

The table allows us to investigate whether there was an improvement and to what an extent. In general, many of the pupils went beyond their initial perceptually based responses, as the categories in the post-test were far more elaborate and complex. Only pupils in group I of the post-test did not show a substantial improvement as compared to pre-test groups. Those who displayed a noticeable improvement were Den, who abandoned a position of total absence of an atomistic view and internalised one of generalising a compensating atomism, and Car, Gus, Fab, Lil and Ref, whose improvement was also remarkable because they discarded their substancialist conception and developed a generalising and compensating atomistic view. The results from this group of pupils lead us to ask if there is a sequence of stages that pupils have to pass through in order to acquire a scientific view. This view is not confirmed by the data, which seems to suggest that it is possible and desirable for pupils to miss out some stages and arrive directly at a scientific view. It was not necessary for Den, for example, to acquire a substancialist view first and then a scientific one. When this pupil was led to compare her view with the scientific one, to criticise her own view in the light of the atomistic one, she was able to construct the latter based on the entire evidence and reasoning presented to support the new idea. It was not necessary for her to change the continuous idea to a substancialist one, and then to a scientific view.

On the other hand, the results show that the presence of atomistic features is a necessary condition for generalisation and compensation when using the model. The students who show a gap in atomistic features were not successful in generalising and compensating.

The results also show that students who were farthest from the atomistic view at the beginning of the teaching had more difficulties in adopting this view. This is especially true for the 7 students of groups 1 and 2, who held a continuous view in the pre-test. Three of them carried on with their previous ideas after the teaching, which shows how ingrained existing ideas

Table 3
Conceptual Evolution on theory of matter in a classroom age 14

<table>
<tr><th colspan="4">results of pre-test</th><th colspan="3">results of post-test</th></tr>
<tr><th>group 1</th><th>group 2</th><th>group 3</th><th>group 4</th><th>group I</th><th>group II</th><th>group III</th></tr>
<tr><td>Gla</td><td></td><td></td><td></td><td colspan="2">Gla</td><td></td></tr>
<tr><td>Rod</td><td></td><td></td><td></td><td>Rod</td><td></td><td></td></tr>
<tr><td>Den</td><td></td><td></td><td></td><td></td><td></td><td>Den</td></tr>
<tr><td>Eli</td><td></td><td></td><td></td><td>Eli</td><td></td><td></td></tr>
<tr><td></td><td>Lin</td><td></td><td></td><td>Lin</td><td></td><td></td></tr>
<tr><td></td><td>Edw</td><td></td><td></td><td colspan="2">Edw</td><td></td></tr>
<tr><td></td><td>Raq</td><td></td><td></td><td></td><td>Raq</td><td></td></tr>
<tr><td></td><td colspan="2">Igo</td><td></td><td></td><td colspan="2">Igo</td></tr>
<tr><td></td><td></td><td>Ale</td><td></td><td></td><td>Ale</td><td></td></tr>
<tr><td></td><td></td><td>Fab</td><td></td><td></td><td colspan="2">Fab</td></tr>
<tr><td></td><td></td><td>Lil</td><td></td><td></td><td colspan="2">Lil</td></tr>
<tr><td></td><td></td><td>Car</td><td></td><td></td><td></td><td>Car</td></tr>
<tr><td></td><td></td><td>Gus</td><td></td><td></td><td></td><td>Gus</td></tr>
<tr><td></td><td></td><td>Ref</td><td></td><td></td><td></td><td>Ref</td></tr>
<tr><td></td><td></td><td colspan="2">Eri</td><td></td><td>Eri</td><td></td></tr>
<tr><td></td><td></td><td colspan="2">Rog</td><td></td><td>Rog</td><td></td></tr>
<tr><td></td><td></td><td></td><td>Res</td><td>Res</td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td>She</td><td></td><td>She</td><td></td></tr>
<tr><td></td><td></td><td></td><td>Bia</td><td></td><td>Bia</td><td></td></tr>
<tr><td></td><td></td><td></td><td>Elv</td><td></td><td></td><td>Elv</td></tr>
<tr><td></td><td></td><td></td><td>Cao</td><td></td><td></td><td>Cao</td></tr>
<tr><td></td><td></td><td></td><td>Dan</td><td></td><td></td><td>Dan</td></tr>
<tr><td></td><td></td><td></td><td>Jan</td><td></td><td></td><td>Jan</td></tr>
</table>

Characteristics of each group (pre-test)	Characteristics of each group (pos-test)
Group 1 - Sensible-empirical definition of states of matter; continuous conception of matter; no conservation of mass Group 2 - Sensible-empirical definition of states of matter; continuous conception of matter; conservation of mass	Group I - Incomplete atomism, with vestiges of discontinuous and substancialist ideas; conservation of mass; absence of generalisation and compensation of disturbances; absence of relationship between different concepts of states of matter
Group 3 - Sensible-empirical definition of states of matter; discontinuous conception of matter; substancialism; conservation of mass	Group II - Complete atomism; conservation of mass; difficulty in generalising and compensating for disturbance; relationship between different concepts of states of matter
Group 4 - Sensible-empirical definition of states of matter; discontinuous conception of matter; conservation of mass	Group III - Complete atomism; conservation of mass; complete or almost complete capacity to generalise and compensate for disturbance; relationship between different concepts of states of matter

may be and how they may survive many stages of instruction, and continue even when instruction is finished. It also leads us to speculate that the absence of a discontinuous view seems to be an ontological and epistemological obstacle greater than substancialism. Both this hypothesis and the 'step over stages' hypothesis must be checked when we examine the teaching process in the classroom, in a future paper.

CONCLUSIONS

We consider that the choice of different categories to analyse the pre- and post-test as well as the hierarchy among these categories enable us to detect the conceptual evolution in a well-defined way, discriminating not only between children who acquire a scientific view and those who remain with some previous ideas, but also between the children in whom new ideas are stable and generalised and those in whom new ideas are too fresh and cannot be generalised. These categories resulted from an analysis of the conceptual profile of each concept.

From the results of pre- and post-tests, analysed according these categories, we can draw several conclusions about the relationship between different notions in an conceptual profile. Concerning the physical states of matter, the data confirm our expectations that the new atomistic concept can explain some features of the previous sensible and empirical concepts, without denying them. In this sense, the teaching did 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 can retain all the ideas that they had before. Nevertheless, we expect that those who have changed their profile and achieved consciousness of this process can recognise different domains of each idea as well as their hierarchical framework, where some ideas explain and subsume others.

This change of conceptual profile also happens with the theory of matter. 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 our research, 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 use their primary model to compensate for disturbances, are conscious of their profile, and use each notion at an appropriate moment.

Children who acquired an atomistic view but had no consciousness of their conceptual profile could use their realistic view of matter when faced with a disturbance, a problematic situation. This is what happened with Rog and She, who used an atomistic approach with almost every problem but when faced with a disturbance returned to a substancialist view.

The notion of a conceptual profile enables us to deal with conceptual evolution in the classroom not as conceptual change, but as a change, accompanied by the acquisition of consciousness of the student's conceptual profile. We 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 a scientific viewpoint. It has also been used to evaluate the conceptual evolution, by selecting different categories within a hierarchy that allow the tracing of 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, in a more precise way, 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.

ACKNOWLEDGEMENTS

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 and Phillip Scott for their suggestions in the first draft of this article.

REFERENCES

AMARAL, L.O.F. (1991). *Sobre a Hipotese Atomica e seus opositores ilustres*. Belo Horizonte, mimeo, Icex-UFMG.

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

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. To appear in R. Giere (Ed.). *Cognitive models of Science: Minnesota Studies in the philosophy of Science*. University of Minnesota Press.

CLAPARÈDE, E. (1946). *L'education fonctionnelle*. Neuchatel: Delachaux et Niestle.

DORAN, R. (1972). Misconceptions of selected science concepts held by elementary scholl children. *Journal of Research in Science Education,* 9(2): 127-137.

DRIVER, R. (1985). Beyond appearence: The Conservation of Matter under Physical and Chemical Transformations. In Driver, R., Guesne, E. & Tiberghien, A. (Eds.) *Children's Ideas in Science*. Milton Keynes: Open University Press.

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

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.) *Classical Scientific Papers - Chemistry*. London, Mills & Boon, 1968.

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

GRIFFITHS, A.K. & PRESTON, K.R. (1992). Grade-12 students' misconceptions relating to fundamental characteristics of atoms and molecules. *Journal of Research in Science Teaching,* 29(5): 611-628.

HEWSON, P.W. & THORLEY, R. (1989). The conditions of conceptual change in the classroom.
International Journal of Science Education, 11(5): 541-553.

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.

MORTIMER, E.F. (1990). Explicacoes dos estudantes para transformacoes fisicas baseadas no modelo corpuscular. Caxambu: *Resumos da 13a Reuniao Anual da SBQ,* p. ED-07.

NIEDDERER, H., GOLDBERG, F. AND 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*. Kiel: IPN, p. 10-28.

NUSSBAUM, J. and NOVICK, S. (1978). Junior High School Pupils' Understanding of the Particulate Nature of Matter: An Interview Study. *Science Education,* 62(3): 273-281.

NUSSBAUM, J. and NOVICK, S. (1982). Alternative frameworks, conceptual conflict and accommodation. *Instructional Science*, 11: 183-208.

PEREIRA, M.P. and PESTANA, M.E.M. (1991) Pupils' representations of models of water.
International Journal of Science Education, 13(3): 313-319.

PIAGET, J. e INHELDER, B. (1941). *O desenvolvimento das quantidades fisicas na crianca. Conservação e atomismo*. Rio de Janeiro, Zahar.

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

POPPER, K.R. (1972). *Objective Knowledge. An evolutionary approach*. Oxford: Oxford University Press.

POSNER, G.J., STRIKE, K.A., HEWSON, P.W. and GERTZOG, W.A (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education,* 66(2): 211- 227.

SERE, 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.

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.

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

VYGOTSKY, L.S. (1962). *Thought and Language*. Cambridge: MIT Press. Translated from

Myshlenie i rech (1934) by Eugenia Hanfmann and Gertrude Vakar.