NEW TRENDS IN STUDIES ON CONCEPTIONS IN SCIENCE

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SUMMARY

More than two decades have passed since the need was seen for more attention to be paid to students' conceptions concerning the science content (see Driver and Easley, 1978). During these twenty years, a large number of studies have been published (Driver *et al*., 1989; Carmichael el al., 1990; Hierrezuelo and Montero, 1991; Pfunt and Duit, 1994, among others). There have also been many accomplished critiques on terminology, theory and methodology context.

In this paper we have carried out a bibliographic review of the most important critiques of studies into conceptions. We offer proposals and suggestions as a result of this review and our own investigations, which may help the science teaching profession to better understand students' conceptions.

INTRODUCTION

The search for students' conceptions on certain science topics has constituted the main research theme of the vast majority of studies published within the field of Science Teaching (Moreira, 1994; Gil, 1994; Pfundt and Duit, 1994). Most of these studies have been carried out from the perspective of "*social constructivism*" (Solomon, 1994; Gilbert, 1995), which is a movement that explores the ideas of the learner. This kind of constructivism is quite extended nowadays, both in the theory and practice of education (for example: Castorina, 1998; Marín, Solano and Jiménez Gómez, 1999).

However, over the years, despite the large number of studies published, several authors have questioned, one way or the other, the results and even the continuation of this particular line of research, for example:

- Duschl (1994), director of the Journal *Science Education*, points *to examples of the misdirection of problem choice in science education research today:... the high number of weak reports of attitude and misconception studies that we receive. ...Unfortunately, most "bandwagon" reports are typically weak because they do not provide developed links to past research, make clear contributions about future directions to take or questions to ask, or provide information about how to improve a research design and methods. ...Another indication of poor problem choice is the number of studies that continue to examine and merely describe students' or teachers' alternative conceptions or misconceptions of science. ...Many of the studies we presently receive, however, like the attitude studies mentioned above, suffer from a lack of depth and discussion of implications for theory or practice. It is time to move forward. Without any investigation and analysis that helps to further an understanding of either the source of the conception or of the strategies involved (learners' and teachers') with using the conceptions, the research is simply descriptive.*
- Gilbert (1995), in an article published in the magazine *Studies in Science Education,* entitled "*Studies and fields: directions of research in science education*", affirms *that is somewhat surprising that there have been so few papers which report on "patterns of understanding". It is only very recently that research reports of cross-age studies, which are essential if progression in learning is to facilitate, have appeared; e.g. Driver et al. (1994). Two factors may be at work here. Firstly, there are many concepts to be inquired into and only a few researchers, so relatively few high quality primary papers have appeared on any given concept, and, secondly, much research funding is short-term, which precludes the conduct of genuine longitudinal studies.*
- Gil (1996), when referring to the new tendencies in science education, considers that, as far as conception studies are concerned, this line of research should be dropped in favor of others, and he also writes about his predictions for the development of research in science education over the next few years: *In the first place, concerning today's most developed line of research, I believe that a*

> *displacement from the detection of preconceptions (using instruments which, in general, give information about pupils' immediate answers and reactions) to the study of the "zone of potential development" (eliciting what pupils can think or do when we facilitate a reflexive and critical work) is necessary. In other words, the abundant results from alternative conceptions show, in my opinion, a student's superficial approach to the situations studied, facilitated by the instruments used. In my opinion equally, as important as these results, are those obtained when we put pupils in the situation of thinking in a more reflective way. So we can expect that this approach will displace the simple detection of alternative conceptions. The evolution of the research in alternative conceptions involves another essential change: overtaking the conceptual reductionism which has characterized, in general, this research and the derived teaching proposals. Taking both the conceptual, procedural and attitudinal aspects into consideration will increase the efficiency of the constructivist approach and facilitate the consensus on science learning as an orientated research......*

A reading of these criticisms seems to lead us to a position where descriptive studies of conceptions are left aside, since "the existing catalogue of such conceptions is already quite extensive". However, there is another interpretation, which invites us to clarify the current state of this particular line of investigation, and leads to perform a critical and reflexive study of the results of previously published studies. The line of argument would go thus:

1. Show that the conceptions research line has not progressed since its beginning (late 70's)]
2. Analyze the possible causes for this lack of progression.
3. Point out new research directions to escape the current situation.

The development of these last three aspects constitutes the foundation on which this paper is based. The main objective is to offer a theoretical context and a methodology capable of obtaining more and better information from the student, which would to help improve teaching programs and learning about science.

2. Have there Been any Improvements in the Results Obtained in Studies of Conceptions through the Years?

A Lakatosian analysis performed by Gilbert and Swift (1985) comparing the contributions of Piaget's theory to those of the Alternative Conceptions Movement (ACM) concluded that Piaget's theory was undergoing a regressive period while the AMC was showing signs of progression.

According to Lakatos (1974 and 1983), the main criterion for determining whether a theory is progressive is its capacity to predict new events, or what is the same, whether its theoretical development anticipates its empirical development. This criterion is only valid if it is used to compare competing programmes, which is the reason why Gilbert and Swift apply it to the two above mentioned tendencies. However, Marín and Benarroch (1994), comparing the empirical contributions on conceptions related to matter's mechanical and corpuscular nature, concluded that it is not clear that ACM's contributions surpass those of Piaget. This latest statement seriously questions the progression of the ACM.

Following this line of criticism, Jiménez Gómez, Solano and Marín (1997) analyzed the degree of progression of the ACM using one Lakatosian requirement, perhaps the least demanding, which examines whether theory brings any new empirical data the study of conceptions. If there had been any progression in the theoretical framework, it should also have been evident in the data of published studies.

To achieve this objective, Jiménez Gómez *et al.* (1997) chose a topic and a representative sample of research on that topic for the period under study (before and after 1985, when Gilbert and Swift's study was published) and established certain criteria to make comparisons. These are presented below.

Mechanics was chosen since it is one of the subjects where students' conceptions have been most studied (Moreira, 1994). However, the enormous number of articles found led us to restrict our investigation to the principles of Dynamics, more specifically the concept of force and laws related with it.

Another problem was to choose representative samples of research into students' conceptions concerning force. Most research along these lines is published in the minutes of congresses and meetings, so they are frequently difficult to obtain. For this reason, we opted only for these articles published in journals specializing in Science Teaching. However, this still meant a very large number and so we decided to concentrate on articles published in the following journals, which, besides being easily available (in Spain) cover the object of our research: *Enseńanza de las Ciencias, European Journal of Science Education (*now*: International Journal of Science Education), Physics Education* and *Science Education.*

We excluded articles dedicated almost exclusively to theoretical discussion even though they may occasionally make reference to students "conceptions" on force since they do not offer methodological proposals or results. In total, 29 articles were chosen and classified into three categories.

Type 1: Works which categorize students' replies according to their similarities and differences, expressed as percentages. The results and conclusions, which are basically inductive, are linked with the peculiarities of the physical facts presented in the questionnaire. We have denominated this group of studies as *descriptive-physical fact dependent*.

Type 2: Works which, besides using the above described procedures, attempt to establish relationships between the different groups of answers corresponding to the questions on different physical facts. The applicability of the conclusions reached in this type of study is greater than that of the first type, to such an extent that the conclusions may sometimes reach a degree of generality that is not implied in the facts contained in the test. Some authors make predictions as to the possible answers of students to situations not presented in the questions. As in the first group of studies, the data are interpreted from the point of view of the logic of the content. This category of study is referred to as *descriptive-physical fact independent*.

Type 3: The third group is composed of works which establish relationships between the categories system used to classify the students' answers and aspects or variables shown to be relevant in the cognitive structure of the student, such as cognitive style, short and long-term memory, mental operations, etc. We refer to this type of study as *descriptive-relational* since they only use descriptive techniques to relate variables, but do not establish relationships between the students' answers and those basic cognitive variables contained in a proper theoretical cognitive context. Table 1 shows the authors classified according to the above three categories.

Table 1. Classification of the articles selected

Descriptive dependent	Descriptive independent	Descriptive relational
Helm 1980, Gunstone and White 1981, Ivowi 1984, Terry and Jones 1986, Clement *et al.* 1989, Brown 1989, Kruger *et al.* 1992, Galili 1993	Viennot 1979, Watts and Zylbersztajn 1981, Watts 1982, Watts 1983, Maloney 1984, Ruggiero *et al.* 1985, Terry *et al.* 1985, Noce *et al.* 1988, Boeha 1990, Villani and Pacca 1990, Finegold and Gorsky 1991, Thijs 1992,Galili and Bar 1992, Reynoso *et al.* 1993, Bar *et al.*,1994, Twigger *et al.*,1994, Kuiper and Mondlane 1994, Montanero *et al.* 1995	Selman *et al.* 1982, Bar 1989, Acevedo *et al.* 1989

Note the small number of studies classified as descriptive-relational makes this group unrepresentative, and that the methodological characteristics used in the descriptive-physical facts dependent group are weaker than those contained in the independent group. For this reason we consider it sufficient for our analysis to concentrate on the 18 articles classified as descriptive-physical fact independent.

A comparison of the different studies classified as "descriptive-physical fact independent" allowed Jiménez Gómez *et al*. (1997) to reach the following conclusions:

1. Lakatos' criterion (1974, 1983) helps to determine whether a theory is progressive, based on its capacity to anticipate new events, or what is the same, whether its theoretical development anticipates its empirical development. If this is applied to the different studies on conceptions, it can be seen that the research line used to determine students' conceptions on force shows no signs of progression, or, at least there is no evidence of such, judged from the studies selected since all, regardless of their date of publication (79-85 or 85-95), are

characterized by a strong empirical nature and theoretical development is not seen to anticipate results.

2. Some progress can be seen in the last decade (1985-1995) in certain aspects such as identification and description of students' answers to a greater diversity of physical cases. However, no progress was perceived in:

   a) The number of conceptions held by individuals and which have been described in studies published before 1985.
   b) The global dimension with which individuals interpret physical laws. Thus, Viennot (1979) and Watts (1983) show that students globalize the concepts of force, energy and momentum but they do not look into this psychogenesis of the concept of force (like piagetiam works did).

The above mentioned limitations have led us to analyze their possible causes, which are related, we conclude, to the methodology used.

3. Methodological Characteristics of Studies Related to Conceptions

In Solano, Jiménez Gómez and Marín (2000) and Marín, Solano and Jiménez Gómez (in press), the most relevant methodological characteristics of the studies they analyzed on conceptions are the following:

1. The replies of the students in response to the situations and questions presented are more or less implicitly catalogued and interpreted by taking *the academic content as reference*. This is the most general characteristic and one which conditions the rest.
   Could any other point of reference be taken? The need to use a theoretical cognitive context closer to the knowledge of the student has already been demonstrated. For this reason, one of the principal ideas behind gathering information has been to describe the bases used in the studies analyzed for making decisions, designing tests and for evaluating and cataloging data, etc., since, if inappropriate, the information may easily be skewed and misrepresented. In our opinion, the academic content is not an appropriate reference since notable differences exist between this and the cognitive content of the student (Marín and Jiménez Gómez, 1992).
2. *In most cases conceptions are delimited inductively and in a descriptive way* (no models are used to explain their presence or their possible relation with other constructs of the student's cognitive structure). These characteristics are closely linked with the above since the absence of models to explain how the student organizes, develops and carries out his/her mental activity, means that the

researcher does not normally have any expectation or hypothesis as to what might be found or how the information is best extracted from the student.

3. *It is not common practice to analyze the validity and reliability of the information obtained from the students*. In the search for and interpretation of such a complex phenomenology as cognitive development, certain measures should be taken simultaneously and systematically. These include the need to:

   – Differentiate the replies which reflect some scheme of knowledge from those which are simply inventions or given "under pressure"; also, responses "induced" by the type of question posed by the researcher or due to the student’s lack of interest.
   – Analyze the coherence and categorization of the data, treating such data as a matrix of cases (subjects interviewed) and variables (categories), making correlation studies, grouping cases according to the similarity of replies (clusters analyses), correspondence analyses, etc. All this would make it possible to verify whether the orders established in the categorization were more or less correct with respect to the general order of the data (internal validation).
   – Make evolutive studies involving samples of different ages, so that it is possible to discriminate groups of data which are best adapted to a given evolutive direction from others which present anomalies in respect to this direction (Marín, 1995, Benarroch, 1998).
   – Compare the results concerning a given unknown aspect with others related with the student and which are better know such as the cognitive level, field dependence-independence, replies to a test of proven reliability, etc.

4. *The information taken from “what a student knows” is very restricted*. The quality and quantity of the information taken from the students is seriously restricted if inductive procedures are used, but if the three previous conclusions are taken into account together with external factors linked to the types of knowledge which a student may contain in his/her cognitive baggage, we observe that:

   a) At the declarative knowledge level only those ideas directly related with the topic are taken into account. However, there are two cases in which it is not usual to detect student conceptions:

      a1) Ideas which are not linked to the content in an adult scientific logical sense, but which are linked for the student to such an extent that they can be used to understand or assimilate the content when it is explained by the teacher (Piaget, 1977). Put another way, the academic content refers to objects, situations, phenomenologies, which make it possible to prepare certain situations and questions which can be answered adequately if one possesses this content. The student possesses a knowledge in this respect which permits him to give replies, although they are far from the "correct" one.

a2) Ideas which are in an evolutive phase “far” from the “correct” content (Piaget and García, 1973); that is, at the moment the test is taken, the student possesses ideas which are poorly developed, intuitive or preoperative. These would be sufficient for him/her to reply to the questions but after a certain (perhaps quite long) time during which such ideas would develop and be enriched, they would have permitted a more correct answer or, at least, a more appropriate one.

The fact that in both cases the student’s ideas are different from the academic does not mean they are less important since they can be used to understand or assimilate the teacher’s explanation of a given content. Ideas which are unlinked to the content in an adult scientific logical sense may be linked for the student (Piaget, 1977). This type of idea is very difficult to detect if only the academic content is taken as reference in the search for information.

b) The students’ cognitive capacity both intellectual (to classify empirical data, infer inductively, reason proportionally, to control variables, formulate hypotheses, etc.) and motor skills (the ability to construct educational material or experimental set-ups) are almost completely absent from these studies despite the fact that such capacities are determining factors in student performance in science (e.g. Shayer and Adey, 1984, Niaz, 1991, Lawson, 1993).

According to this, we believe that the lack of contributions for the description of new conceptions during the period between 85-95, compared with the period 75-85 (see Jiménez Gómez *et al*., 1997), is due to:

- The way of treating the search for conceptions and to the fact that the same methodological “style” was kept in both periods.
- The little or non-existent progression in using a suitable theoretical foundation.

Similar methodological characteristics have been found in all the studies analyzed from the periods 75-85 and 85-95, and there seems to be no clear tendency towards abandoning old ways or assuming new ways of approaching the search for students’ conceptions. The above mentioned shortcomings, both methodological and theoretical, have been pointed out by other authors such as:

- Moreira (1994), who, in his review of the articles published by the journal *Enseńanza de las Ciencias* during its first 10 years, point out that more than a third dealt with student’s conceptions, which, in most cases, had no theoretical foundation whatsoever. He continues that making references in the introduction of an article to other authors or theoretical contexts which are not indeed used in the article itself, cannot be considered as a theoretical foundation. Therefore, he wonders if research in Science Teaching should continue if there is no theoretical basis and, following this trail of thought, if it is possible to carry out relevant research at all.

- Sanmartí and Azcárate (1997), director and associate director of the journal *Enseńanza de las Ciencias*, affirm that most of the articles they receive have to do with the description of conceptions and that, after a long period of mostly descriptive research, some interpretative studies are overdue.

It is also interesting to point out that there are only three studies classified as descriptive-relational (see table 1), where relations between students' answers and cognitive variables are established, although such relations are not established in a cognitive theoretical background. If the object of the research is only to understand the academic knowledge which students have gained from previous years' science classes, the methodological characteristics observed in the studies we have analyzed would have a certain validity since they are suitable for comparing and contrasting this knowledge with a standard (in this case the academic content itself). In such a case, a questionnaire could closely resemble the tests which are frequently used to evaluate a student's progress at the end of an academic year.

The problem is that a student spontaneously develops many conceptions through interaction with the social, cultural and physical environment. In such a situation, the academic content is not the most suitable reference for assessing this knowledge and the methodologies described above are inadequate because, apart from his/her academic learning, the learner has a lot of other knowledge obtained from experience outside the school or academic context. Part of this knowledge may be connected to the academic, but much of the student's spontaneous cognitive knowledge will not (Novak, 1982; Sebastia, 1993; De Posada, 1996; Marín, 1997; Pozo and Gómez Crespo, 1998).

It is reasonable to think that the spontaneous knowledge generated by the student differs quite a lot from the teaching content, so that such spontaneous knowledge is not relevant for the teacher when drawing up a teaching program. Thus, a teacher or researcher who follows this reasoning will only look for the student's "ideas" about what is to be taught. However, it is widely accepted that a student cannot understand or apply something new if some part of his/her existing knowledge is not activated in the process. It is therefore likely that in order to learn the content of what is being taught by the teacher, the student will initially try to use some part of the academic knowledge (if any) s/he has; if the student has no such knowledge s/he will activate some spontaneous scheme although, from the perspective of adult or academic logic, this scheme may not be related to what is being taught.

If a theoretical context such as Piaget's Genetic Epistemology is followed, we will find that students' answers to Piagetian tasks are classified in different levels depending on the operational schemes used by the student in order to solve the tasks. Nevertheless, when pairs of experiments performed by Piaget are compared, based on similar logical and operative structure [problems related with the composition of force depending on intensity or direction (Piaget *et al.*, 1973), with the notion of velocity in two different experiments (Piaget, 1946), with length preservation (Piaget, Inhelder and Szeminska, 1948) as opposed to matter, weight and volume conservation (Piaget and Inhelder, 1971) and finally, problems involving variables control using pendulums or flexible rods (Inhelder and Piaget, 1972)] we find individual differences that can only be explained if the existence of specific knowledge schemes linked to the context of the task is admitted. These specific knowledge schemes would be as important as the operational schemes (Marín, 1994a).

From the above, we can infer the necessity of using two theoretical contexts on which to base conceptions research:

- One of these contexts, the exclusively scientific one, offers information which is often skewed, since it deals with the psychological interpretation of answers provided by the students. Many teachers and researchers are only concerned with students' "ideas" related to academic contents, but they forget other, such as the those related to students' processing capacity when resolving a task.
- The other, the strictly psychological context, does not seem to be the only solution to the problem either since a child's knowledge comes from his interaction with the physical environment, while the content to be taught belongs to the field of science.

Finally, it is important to mention the existence of some kind of a consensus as regards:

a) dropping descriptive research on conceptions and, instead, aiming at evolutive or cross-age research, in order to learn how students' knowledge progresses in relation to the teaching content.
b) preparing a theoretical context in order to identify, describe and interpret conceptions, and
c) ensuring that such a theoretical context takes into account the student's cognitive development and Science Epistemology. These two aspects should complement each other within a global theoretical context useful for investigating "what the student knows" about the content to be taught.

4. Our Theoretical and Methodological Proposal for Conceptions Research

In order to be as clear as possible, we will go from general statements to more specific ones, dividing our contributions into three different areas: theoretical context, methodology used to obtain educationally interesting information from the student and, finally, the most relevant results from our conceptions research.

4.1. – Theoretical Context

The strong influence of Piaget's work during the 70's has conditioned many of the stated proposals. However, critical comments against it have also been included (see Vuyk, 1985); to this effect, we have tried to incorporate new perspectives from Information Processing Psychology (e.g. Pascual-Leone, 1979; 1983; Case, 1983), which attempts to compensate for certain Piagetian deficiencies. Furthermore, we have included various suggestions from the ACM (Marín, Benarroch and Jiménez Gómez, 2000), whose main grounds have been taken from the theoretical context of which is mainly based on the Philosophy and History of Science. However, for reasons of space, we will only focus on a few of these aspects.

There is a difference between the individual's cognitive organization and the observable expression of this (verbal, symbolic, manipulative, etc.), so that there is some kind of uncertainty in the relationships between the answers we obtain and the real knowledge behind those answers. This means that *an answer does not necessarily represent a knowledge scheme* because it may have been given by chance or invented in "situ", etc. Perhaps the student has the proper knowledge scheme to solve a task but s/he does not activate it (due to cognitive or affective reasons at a particular moment). This would lead us to consider internal knowledge as a potential which students possess but which they are not always capable of applying. This means that the information provided by the student in a questionnaire is important, but the representative model of his/her cognitive organization considered in the research is also important.

The starting point of the cognitive model we present here starts from Piaget's theory (1978) about cognitive structure, but we also introduce, at a lower level, a new family of schemes we call "*specific knowledge schemes*", which are content-dependent (Marín, 1994b; Benarroch and Marín, 1997). The combination in the short term memory of specific and operational schemes, together with the conditions of the task or problem perceived by the student, would be the cause of the different answers provided by the individual: verbal, written, actions, drawing, etc.

When distinguishing the students' cognitive organization as opposed to manifestation, we admit that many answers provided by students in questionnaires do not necessarily reflect their knowledge schemes, maybe because they were made up or given by chance or perhaps because they were forced to answer. Therefore, we can differentiate between significant and non-significant answers. The former are generated by the activation of cognitive structures while, in the latter, the activation of these structures is lower, there is a lower cognitive involvement by the student, less reflection when the structures are generated and, therefore, the replies contain less information about knowledge schemes. Significant and non-significant answers are ends of a continuous "axis" of meaning and the more we move along the positive end of the axis, the greater the reflection and involvement of cognitive structures.

The above mentioned exposition will be of atmost importance in the methodological proposal we make below.

4.2. Methodological Contributions

All the conceptual background to our methodological contributions to conceptions research was developed during the 90's. The contributions were published in different journals but, they are here presented in a condensed manner so that, for reason of space, we will only mention the most relevant methodological aspects:

4.2.1. - The identification of what the student 'knows' depends on the teaching objectives and methods used by the researcher

Marín, Jiménez Gómez and Benarroch (1997) analyze the existence of some kind of relation between the science teaching model adopted and what the researcher expects to find concerning the student's cognitive organization, that is, what the student may learn about certain topic of science. For instance, a researcher influenced by Ausubel's proposal (1982, Ausubel, Novak and Hanesian, 1986) perceives the student's cognitive background as a conceptual semantic network to which contributions can be added by linking "what the student knows" with the contents to be taught; if, on the other hand, we expected the student to transfer what he has learnt to a different context from the academic, then it would be better to apply Piaget's model, since its theoretical framework considers procedural acquisitions as a prerequisite in order to make conceptual knowledge more flexible and operative.

The current tendency of descriptively investigating students' conceptions offers specific and limited information about the content to be taught. Such conceptions, in the way in which were investigated in previous studies, could be enough to design teaching and learning processes leading to understanding the content. But if we intend the student to use the newly gained knowledge in different contexts, then perhaps we need a different methodology to investigate students' conceptions. This new methodology should provide both specific information about the contents to be taught as well as general information related to the stability of the students' assimilation schemes.

In this paper, we defend the necessity of obtaining more educationally relevant information about the student in order to create teaching programs more adapted to their cognitive characteristics and to facilitate both the students' learning process (adaptation to the social, cultural and physical environment) and their mental development.

4.2.2. What are we referring to when using the words conception and scheme?

In the field of *Science Education*, the terms conception and scheme are most commonly used to refer to the students' knowledge of the science topic, although many other terms are also used, such as *children's misconceptions* (Terry *et al*., 1985), *conceptual misunderstanding* (Galili and Bar, 1992), *spontaneous ideas* (Viennot, 1979), intuitive "law" or *spontaneous reasoning* (Viennot, 1979), views (Boeha, 1990), *conceptual framework*, *students' beliefs or students' conceptual categories* (Finegold and Gorsky, 1991), *rules* (Maloney, 1984), *spontaneous models* (Villani and Pacca, 1990), *implicit theories* (Montanero *et al.*, 1995), etc. This diversity, mentioned by some other authors as well (Gunstone, 1989; Furió, 1986; Jiménez Gómez *et al*., 1994, among others), shows the existence of different theoretical positions and ways of proceeding in this research line (Marín *et al.*, in press).

In the context of science teaching, the term *scheme* is used to represent a group of common and coherent concepts (Viennot, 1979), students' ideas which are coherent with their experiences (Watts and Zylbersztajn, 1981; Watts, 1983; Terry *et al*., 1985), perspectives from which the students' answers to different questions can be predicted (Finegold and Gorsky, 1991), a group of ideas which show a certain consistency towards the same concept presented in different problem areas and contexts (Kuiper and Mondlane, 1994), a network of relationships which constitutes the knowledge of facts and phenomena used by a child (Ruggiero *et al.*, 1985), etc.

The term *conception* is associated with categories of replies (Noce *et al.*, 1988), meanings constructed by an individual to make sense of the world (Thijs, 1992), students' ideas extracted from erroneous responses to a physical situation (Galili and Bar, 1992), students' conceptualizations as deduced by the investigator from their descriptions and explanations (Twigger *et al*., 1994), students' explanations of a given physical fact (Montanero *et al.*, 1995), etc.

It seems that different terms are frequently used to refer to one meaning, suggesting that the use of one term does not necessarily imply a definite meaning.

In the field of Cognitive Psychology, the term scheme is frequently used to explain learning, the understanding of texts, the representation of facts, the recognition of visual patterns, etc. (Pozo, 1989).

In Marín and others (2000) the terms schema and conception are put under more exhaustive analysis and, without making any attempt to solve these problems of terminology, they propose to use the word *scheme* as a construct which forms part of the non-visible cognitive network of the subject and reserve the term *conception* to refer to the students' responses The conceptions should have some degree of regularity and be constructed by an inductive process by the science expert as an observable manifestation of the students' cognitive baggage (Brumby, 1979; Nussbaum and Sharoni-Dagan, 1983; Terry and Jones, 1986; Brown, 1989, among others).

We would like to make clear that from here on, the terms *conception* and *scheme* will be used according to the definition mentioned in the previous paragraph.

4.2.3. Is it possible to investigate students' conceptions about any kind of science content?

Students will have a poorly developed knowledge scheme for certain topics of science, while their schemes for some others will show a greater degree of development. The construction of these schemes will depend on interaction with the natural, social or cultural environment. That means students will have less knowledge about electrical concepts (electrical potential difference, electromotive force, electrical resistance, etc.) than about mechanical concepts since most students will have no personal experiences related to the former, while the latter (weight, movement, verticality, etc.) will be more familiar. It is probable that a researcher who tries to find out what the student "knows" about electrical concepts will receive answers where the student feels somewhat coerced, answers made by chance or where something heard before is repeated. Schemes of knowledge play little (if any) role in such replies (also, Hallden, 1999).

We often come across studies where the researcher believes he has perceived certain students' "conceptions", while the truth is those conceptions are only in the researcher's mind (also, Taber, 2000). From this stems the need to analyze how significant the content under study is as a prior step to research, or at least, to study the significance of the proposed questions (Jiménez Gómez and Marín, 1996).

In conclusion, not all the academic content that is being taught is necessarily appropriate to guide research into students' conceptions, for the simple reason that the student probably has no knowledge about much of the content.

4.2.4. How to identify and describe students' conceptions?

In the process of identifying conceptions there is a clear underlying interaction between the researcher's and students' knowledge and thus it is difficult to obtain information concerning only the students' cognitive system, without the knowledge of the person interpreting the data interfering. Therefore, it is necessary:

a) *To be systematic when creating the facts, events, phenomenologies and questions to be included in the questionnaires*.

Once the teaching content, about which students' conceptions will be identified and described, has been chosen, it is advisable to confront students with a diversity of phenomenologies, facts and events which underlie the content to be investigated and to allow them to express their knowledge on the topic (Marín, 1994b; Benarroch, 1998). On the contrary, to ask direct questions about the content, such as "what is force?" or "what is the center of mass?" are not to be recommended (also, Hallden, 1999).

b) *Break up the content into different parts*.

The initial problem a researcher has to deal with when designing a questionnaire is where to start! The first step, already mentioned, is related to the teacher or researcher's knowledge of the content, which should be reflected is the systematic approach applied to the facts and events to be used in the questionnaire.

A second step, complementing the previous one, is to break up the content into different parts, so that each part becomes a unit of study. Despite the absence of fixed rules, it is evident that certain criteria have been used more than others. Some of the most used are:

- Contents which can easily and logically be broken up into different parts. For instance, *the senses* can be divided into 5 parts or be studied globally.
- Contents such as “the composition of forces” can be broken up, depending on the level of complexity: aligned forces of the same magnitude and direction or different direction, etc.

That is not all that can be done in this respect, since it is possible to use the results of other previous studies as a dividing criterion adapting them as hypotheses or as references to be criticized.

Once the content has been chosen and divided into different parts, it is time to look into students’ knowledge; a set of methodological actions, based on the theoretical context previously described, would help avoid skew and distortions. These methodological aspects are:

- **Design of a questionnaire on a specific science content. Contextual strategies variation and factors that influence in the task**

Aware of the difficulties implicit in our methodology, we have decided to illustrate the different methodological actions and orientations, by taking fragments from two of our research contributions:

1. Evolution of students’ knowledge schemes to explain mechanical equilibrium (Marín, 1994b).
2. Evolution of students’ conceptions related the corpuscular nature of matter (Benarroch, 1998).

Despite the different topics under study in both researches, their foundations and methodology do not differ.

Each questionnaire is initially based on the systematic study of the content to be investigated, which leads the authors to design different tasks. For example, in appendix 1 we present task 3, from five tasks designed to cover the content, which deals with “the corpuscular nature of matter” (Benarroch, 1998), while in appendix 2 we present task 1 about “equilibrium when objects are allowed to hang freely”, extracted from a total of eight tasks covering different situations of mechanical equilibrium questionnaire (Marín, 1994b).

Different types of strategies must be used in each task so that the students’ cognitive schemes are more deeply involved. This is why a personal interview should be used, where the researcher shows the student the different tasks through a strategy we call *"confrontation*", which basically comprises two stages:

- *Prediction stage,* where the student is asked to anticipate possible outcomes for a physical fact or event.

See questions 3.1, 3.4, 3.5 and 3.7 of task 3 (appendix 1). You can also see examples in questions 1.a, 1.b, 1.c and 1.e of task 1 (appendix 2).

- *Empirical verification and confrontation stage*, where the researcher or student carries out an experiment, the results of which are confronted with the answers given in the previous stage and with the ones given in this stage.

See questions 3.2, 3.6, 3.8, 3.9, 3.10 and 3.11 of task 3 (appendix 1). Also in questions 1.e, 1.f, 1.g, 1.h, 1.i, 1.j, 1.k, 1.l of task 1 (appendix 2).

In order to obtain, on the one had, the widest possible information from the student concerning the subject under investigation and, on other hand, to be able to discern random or invented answers from those which involve knowledge schemes, we have used what we shall call "*variation strategies*" among which we may distinguish the following:

- *Contextual variation*, which consists of presenting different physical situations with the same underlying research content. The following are examples:

    a) To study student conceptions on the corpuscular nature of matter a questionnaire was constructed which includes different tasks involving solids, liquids and gases. In one such task a water color paint (solid) and wet paint brush are used. The wet pint brush is dipped in the water color and one paints with the resulting color but when a drop of paint is allowed to fall from the paint brush into a container of water no coloration is observed because of the high degree of dilution (see fig. 1). In another task alcohol (liquid) is carefully poured into a test tube containing water. After shaking, it can be see that the height o water descends but the weight remains the same (fig.2). In the third task the compressibility of air (gas) is compared with that of water (fig. 3).
    b) In the questionnaire about "situations of mechanical equilibrium", equilibrium in different contexts is presented, in which the concept of verticality, equilibrium and center of mass come into play. Objects of a simple, regular shape (sphere) are used with a well-defined center of mass. These are hung (fig. 4) or placed on a base (fig. 5). Also two blocks of wood (one pine, the other balsa), in which it is more difficult to identify the center of mass, are used (fig. 6).

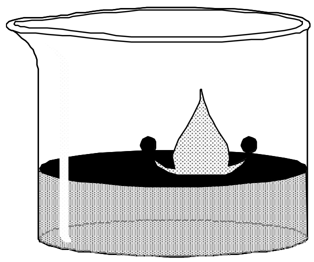

Fig. 1. What happens to the drop of yellow after mixing?

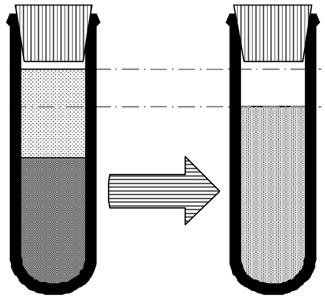

Fig. 2. Why hasn't the weight varied although the height has?

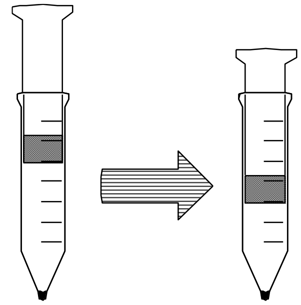

Fig. 3. Why can you push the plunger more with air than with water?

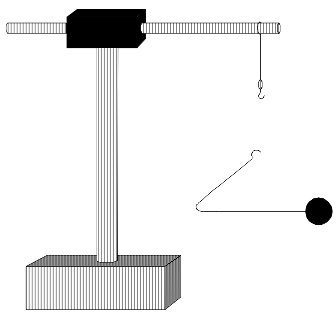

Fig. 4. How does the object end up if it is hung from the hook?

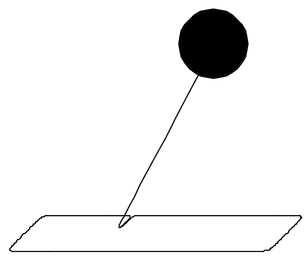

Fig. 5. How far can you push the ball before it falls?

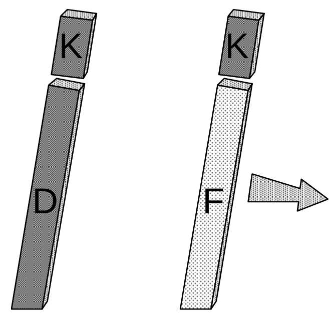

Fig. 6. Why does F fall over when K is put in place, whereas D does not?

- *Relevant variations*, which are modifications of some factors implied in the situation, causing some kind of relevant alteration. Examples:

  a) In figure 1, where small quantities of yellow solute are introduced in the water, the progressive dilution in the solution eventually leads to the absence of color, although the student is aware that the yellow is "somewhere".
  b) In figure 6, although the wooden block K which is put on top of both inclined wood blocks D and F is the same in both cases, only this last one falls down; why? Because inclined wood block F is made out of low density wood.

- *Non-relevant variations*, which are modifications of certain factors involved in the situation, do not imply any kind of relevant alteration. Examples:

  a) In task 3 (see appendix 1), after asking about an image where air is introduced into a syringe, the same thing is done with colored gas. In this case it is easier to "see" its elasticity due to the color changes associated with concentration.

b) In the first task (see appendix 2), we have several objects made out of aluminum wire with a plasticine ball at the end. Because of the malleability of the wire, the objects can be shaped (see drawing), but in all cases, since the wire mass is insignificant compared to that of modeling plasticine, the ball always remains in the same vertical line as the hook. Therefore, variations in the way the wire is molded are irrelevant in relation to the object's position when hung.

Similar techniques to the above were used by Piaget (1946, 1975 and, 1978).

The combination of confrontation between students' answers in the prevision and empirical verification test, and variation strategies (contextual, relevant and non-relevant) increases the possibility that:

a) Students apply their knowledge schemes more thoroughly when answering questions.
b) The degree of regularity in the students' replies can be evaluated by using three criteria:

(i) repetition, or the replies that remain unaltered despite the modifications of the physical situations introduced using both non-relevant and relevant variation strategies.
(ii) generalization, as observed from analogous replies to the physical situations principally constructed from contextual variation strategies.
(iii) Accommodation of the replies to the factors intervening in the task (contextual variation and confrontation strategies).

Variation strategies allow more information to be gathered from students in such way that when the answer shows signs of reiteration, generalization and accommodation, it is reasonable to infer that, after applying a variation strategies (non-relevant, relevant and contextual), the students have used some knowledge scheme or a combination of them.

Note the variation strategies (non-relevant, relevant and contextual) used in the individual interview, are based on the underlying model of cognitive organization, where the organization unit is a knowledge scheme with characteristics of stability and coherence (Piaget, 1978; Pascual-Leone, 1979; Case, 1983; Marín, 1994a,b).

Evolution of students' conceptions can be described from the different conceptions perceived in a large student sample (we usually select 40 students for our studies) with a broad age range (in this study 6-24), in an attempt to obtain a homogeneous representation of the different educational and mental development levels. This number (40) is justified by the fact that after 30, the answers given are repetitions of those previously registered and do not provide new information which might change the system of categories described (Marín, 1994b; Benarroch, 1998).

- **Obtaining data through personal interviews**. Through personal interviews, using *confrontation* and *variation* strategies, each student provides a great amount of information, which demands an audio-visual recording in order to extract all the necessary data to carry out the research (interview example in table 2).

Table 2. Example of part of an interview.

TER (interviewed student's pseudonym. Age: 13,5) ……….TASK 3 (appendix 1)
Interviewer: Do you see this balloon? Let's weigh it...what is the weight?
Student: 14.8 grams.
I: If we inflate it, do you think it will be heavier?
S: Yes, it will. I read in a book that air has a weight.
I: Should we verify it?
S: OK, but I do know it has a weight.
I: And do you believe it? Let's verify it...(It is weighed). What's the weight now?
S: 14.9...you see?
I: Can it be pressed on?...make a drawing before and after pressing.
S: Shall I draw a circle?
I: Whatever you prefer...what do those little spots mean for you now?
S: Well, different molecules and particles, such as dust, oxygen, specks of dust, etc. These are all compressed in one side of the balloon.
I: Smaller?
S: No, just closer together.
I: And what is there between all those spots?
S: I suppose there must be some more.
I: What is in this syringe now?
S: Air...compressed air now...it's the same as the balloon. If I have a lot,...5 can be pressed to 1.
I: Could you make drawings of it?.
S: Yes, just like in the case of the balloon, I suppose the particles, molecules which were carbon dioxide, oxygen, etc.. are now thicker and I suppose when they are compressed, they get more compact, closer together.
I: First separate and then closer together?
S: Yes
I: How about between the spots?
S: I think there are probably areas with no molecules, I don't know if they're everywhere.

I: Areas with nothing in them?

S: I think so...vacuums...I believe if we compress the space where there is nothing, such space will get smaller and the particles closer together, creating a more compact mass.

I: Do you think the same would apply to water?

S: I don't know...I don't think so.

I: Look, I am going to put water in the syringe ...I can't cover it up...I can't reach the water.

S: That's because there is an air mass in .

I: What could I do about it?

S: I don't know...let it out?

I: Right...well, it seems the air won't come out...now. Take a look, no matter how much I press, water can't be compressed.

S: I think water is totally compact, just like air is, although air has gaps between the different particles while I think water is a totally compact mass.

I: Draw the differences.

S: There are molecules in the air, separated by hollow spaces, but in the water...there are particles too.

I: In the water there are particles too?

S: Yes, although those hollow spaces instead of being gaseous, that is, with air in them, they have liquid instead. Maybe that's where the difference is.

I: Yes, but you never drew those water particles before.

S: True, but that's because my last thought had never crossed my mind before...however, now I know there are particles in it too. There's got to be.

- ***Categorization and hierarchization (qualitative phase of data treatment) of students' answers***

In order to classify the data, two complementary and interdependent procedures have been used:

1. One inductive, grouping the answers according to analogies and differences.
2. The other deductive, since the use of theoretical positions and emphasizes some data more than some other, and also gives order to the categories. For instance, the students' answers are analyzed in order to look for newness, distortion and, generally speaking, any kind of transformation of the observable aspects of the task.

As answers are being categorized, they are incorporated into a system of hierarchical categories (empirical categories); this way, each individual's answer to a question or to a set of them are given a category number, which represents the position of that answer in the system of hierarchical categories (see table 3).

Table 3. Obtaining empirical categories for students' conceptions related the corpuscular nature of air and water

Differentiating qualitative features	Empirical category	Students
Both air and water are conceived to be continuous. The explanation for their different compressibilities lies in the very nature of those substances	**1**	Qin, Mor, Tor, Ril, Nil, Her, Vel, Tin
Continuous models with empty spaces only for air (continuous water) or continuous models with empty spaces for both substances	**2**	Lor, Kar, Nav, Sed, Cas
"Apparent discontinuous" models (particles/filled-in background) for one of the two substances. The other continues to be continuous. The continuous substance behaves according to its nature. For "apparent discontinuous" there is a transposition from the macroscopical property to the microscopic background	**3**	Jos, Jun, Mek, Mon, Pat, Gos
Apparent discontinuous models (particles/filled-in background) for both substances, that is, there is a transposition from the observed properties to the microscopic backgrounds. The explanation for this is based on the nature of those backgrounds	**4**	Raq, Sor, Par, Gan, Dan, Ber, Men, Fan, Gim
"Rudimentary discontinuous" models (particles/vacuum) for the air. Water remains "apparently discontinuous" (water particles/filled-in background). The explanations try to be a little more elaborate than a mere transposition to the microscopic level	**5**	Ter, Cat, Mar, San, Rom
"Rudimentary discontinuous" models (particles/vacuum) for both substances, despite not being an explicative enough system help understand the different degrees of compressibility. Unblocked explanations	**6**	Can, Bat, Lin
"Rudimentary discontinuous" models (particles/vacuum) for both substances, introducing strategies or dispositions (water particles stuck to one another) which explain the different degree of compressibility. Unblocked explanations	**7**	Fol, Kem, Fat

Advanced discontinuous models (particles/vacuum/forces) for both substances, which comes from the necessity to explain the different degrees of compressibility	**8**	Pel, Win, Cap
Academically accepted model (particles /vacuum / forces / movement) both for water and air	**9**	Fer

- ***Quantitative treatment of the date***

As previously mentioned, not all the students' answers are declarative constructions built from their knowledge schemes, which is why we need to evaluate the information obtained after it has been collected. Contrasting students' answers by variation (context, relevant or irrelevant) and confrontation, allows us to determine the regularity of the answers and, therefore, to identify and describe the conceptions involved.

These variation strategies behave as control of the data taking process, making it possible to differentiate between the information which comes from the students' knowledge schemes and answers given at random, made up, etc.

Data provided by *confrontation* and *variation* strategies, combined with statistical modules (*principal components analysis*, *different cluster analyses* and especially, *correspondence analysis*), permit the classification of answers into relevant and less-relevant. However, no matter how good a group of statistical techniques are, if they are used without a questionnaire designed according to the confrontation and variation strategies, they will have less capacity to distinguish between relevant and non-relevant answers. It is the *combination of qualitative and quantitative techniques*, before and after data treatment, that provides the capacity to discriminate. Based on the statistical treatment of empirical strategies, others, more precise, can be obtained, which we call "*structural categories*" (Marín, 1994b; Benarroch, 1998).

Table 4 is a restructuring of table 3. These new structural categories, we think, provide more information on students' knowledge concerning the phenomena being studied.

Table 4. Description of the structural categories for students' conceptions related the corpuscular nature of air and water

Structural Category	Structural category Description	Empirical Category	Students
1	Students conceive air and water as continuity, even after seeing their different compressibilities.	**1**	Qin, Mor, Tor, Ril, Nil, Her, Vel, Tin
2	Students adjust their unstable models to the new compressibility experiments, achieving continuous models with empty spaces, whether it is just for air (continuous water) or for both substances.	**2**	Lor, Kar, Nav, Sed, Cas
3	Apparent discontinuous models (particles on filled-in background) for one of the two substances. The other continues to be continuous.	**3**	Jos, Jun, Mek, Mon, Pat, Gos
4	Apparent discontinuous models (particles on filled-in background) are achieved for both substances.	**4**	Raq, Sor, Part, Gan, Dan, Ber, Men, Fan, Gim
5	The minimum level reached is particles/vacuum for the air and particles/filled-in background for the water. However, most students conceive particles/vacuum models for both the air and water	**5**	Ter, Cat, Mar, San, Rom
		6	Can, Bat, Lin
		7	Fol, Kem, Fat
		8	Pel, Win, Cap
		9	Fer

In this way, Benarroch (1998) managed to identify and describe students' conceptions as they matured in many situations that can be explained in corpuscular terms. Granular solids, liquids and gases were mentioned, since these three states have clear perceptible differences in their nature. For reasons of space, we only present students' conceptions about phenomena related to the different compressibilities of air and water. However, these conceptions, along with others described for the remaining physical situations, helped identify regularities common to all of them. The existence of these can only have the following explanation: their regularity is closer to the knowledge schemes which give rise to conceptions.

The structural categories of table 5 (obtained from students' answers to task 3) can be matched to their respective conceptions (obtained from the questionnaire as a whole), which, by the methodology used, reflect five specific knowledge schemes on the corpuscular nature of matter. The five conceptions can be hierarchised and after such a process we call them explicative levels (see Table 5).

To be exact, five different explicative levels were reached in students answers (Benarroch, 2000). These levels which are successive approximations of the model adopted by scientists, show how conceptions progress from the macroscopic to microscopic, moving from the idea that non-directly observable hypothetical objects exist, to the idea that there are empty spaces between the objects, and that these spaces are a vacuum.

In table 5, columns 1 and 2 correspond to explicative levels; column 3 to structural categories. In the fourth column an example of significant answers for each level is shown; the fifth column provides the pseudonym of the student interviewed. Finally, in the sixth column, the students' operational level is mentioned, to illustrate that it is possible to associate an idea of "real particles" to preoperational and concrete subjects, and "hypothetical particles" to formal operational level.

Table 5: Relation between structural categories and explicative levels about matter

Level	Explicative Levels Referring To Matter	Structural category for students' conceptions related the corpuscular nature of Air And Water	Examples of answers (Why is air compressible and not water?)	Students (pseudonym)	Operative level According To Piaget
I	Matter is perceived as continuous and static, unless the opposite is observed macroscopically	Students conceive air and water as continuity, even after seeing their different compressibilities	*"...because air can be compressed, but not water."*	Quin, Vel, Tin, Ril, Her, Nil, Tor, Mor	< 2B/3A REAL PARTICLES
II	Matter is perceived as: - Continuous, packed with particles, or - Continuous with hollows.The option taken will depend on perception	Students adjust their unstable models to the new compressibility experiences, achieving continuous models with empty spaces, whether it is just for air (continuous water) or for both substances	*"...Air has empty spaces inside, but not water...those empty spaces can be reduced in size"*	Pat, Cas, Nav, Kar, Sed, Men, Mek	
III	Matter is formed of particles and empty spaces between them. There is no need for a vacuum between the particles	Apparent discontinuous models (particles on filled-in background) for one of the two substances. The other one keeps on being continuous	*"... Air particles can get closer to each other because their empty spaces are full of air ...in water: the empty spaces are filled with water and particles can't get any closer.... particles are next to each other and thus, they can't get any closer..."*	Lor, Mon, Ter, Gim, Gos, Par, Raq, Gan, Sor, Jun, Mar, Dan, Rom, Jos, Fan, Ber, Kem	> 2B/3A HYPOTHETICAL PARTICLES
IV	Particles and necessary vacuum between them form matter	Apparent discontinuous models (particles on filled-in background) are achieved for both substances	*"...Air particles have bigger empty spaces than water particles.... they are next to one another..."*	Can, Lin, Bat, Fol, San, Cat, Fat, Pel, Win, Cap	
V	Movement is necessary and there is a causal coordination with vacuum. We come to the academically accepted model	The minimum level reached is particles/vacuum for air and particles/filled-in background for the water. However, most consider particles/vacuum models both for the air and the water	*" There are repulsion forces between water particles which impede them from coming closer*	Fer	

4.2.5.– New tendencies in the conceptions research line parallel ours

The methodological proposals made above, match current tendencies in conceptions research. For example:

- Interest is shifting from alternative conceptions, previous ideas, etc. such as the regularity of students' answers, towards constructs such as mental models, schemes and implicit theories which help explain conceptions (Vosniadou, 1994;

Harrison and Treagust, 1996; Moreira, 1994; Greca and Moreira, 1998; Pozo and Gómez Crespo, 1998; Oliva, 1999, among others).

- The heterogeneous image of conception studies is being replaced by a more homogeneous one (Pozo *et al*., 1991), although not as homogeneous as Piaget's (Inhelder and Piaget, 1972). Current information shows that conceptions are not due to random answers, although the dispersion detected cannot be explained just by using coherent knowledge schemes; in other words, some kind of consistency is admitted in students' answers, and regularity between those answers is being analyzed in a variety of situations.
- Pen and paper questionnaires are being replaced by semi-structured interviews or dialogues with evident metacognitive intentions (Gutiérrez and Ogborn, 1992; Vosniadou and Brewer, 1992;, 1994). The students first compare their first answers with the empirical data or the views expressed by an expert, teacher or some kind of written information, and secondly, if needed, take responsibility for the necessary changes. Cross-age studies, implying samples with broad age ranges, have significantly increased during this decade (see Galili and Bar, 1992; Reynoso *et al*., 1993; Bar *et al*., 1994; Twigger *et al*., 1994; Kuiper and Mondlane, 1994; Montanero *et al*., 1995; Benson *et al*., 1993).
- There is growing preoccupation for a theoretical basis, beyond the pragmatism and inductivism which characterized the first studies in this research line. The absence of a theoretical background has been continuously pointed to as one of the reasons leading to failure (Sebastia, 1989; Gil, 1994; Moreira, 1994; Marín, 1995). Different contributions (Chi, 1992; Vosniadou, 1994; Lawson, 1994; Glynn and Duit, 1995; Harrison and Treagust, 1996; Pozo and Gómez Crespo, 1998) suggest a convergent step should be taken since certain epistemological and ontological positions are incompatible.

As far as new studies within the described methodological and theoretical framework are concerned, besides application to little studied new teaching topics (nutrition knowledge evolution, digestive system, locomotion system, reflection, earth, orientation, etc.), many possibilities exist:

- Apply this methodology to procedural contents (e.g.: proportional reasoning, variables control, classification capacity, etc.)
- Apply the methodology to manual abilities (ability to create balances, handle pipettes, to look through a microscope, etc.)
- Perform, after the evolutive delimitation of conceptions, teaching content sequences, and then use them as criteria to carry out critical studies of text books.

This theoretical work, along with the methodology, constitutes the foundation for our research.

5. Reflections on the Significance of Research into Conceptions

In the field of Science Teaching there have been more or less implicit suggestions that there is a need to stimulate new research lines to the detriment of others, such us conceptions research line (Gil, 1996; Dusch, 1994; Osborne, 1996; Gilbert, 1995; among others), since, it is maintained, the conceptions catalogue is already large and quite complete. However, in the light of our research, we do not think it is pretentious to affirm that we should "*retrace our footsteps*" to criticize previous studies using a more accurate methodology so that we can separate "*conceptions*" which only exist in the mind of the researcher (rational reconstruction based on students' non-significant answers given at random, made up or "forced") from other *conceptions* which reflect some scheme of knowledge.

It has been said that a large amount of conceptions studies are made with an eye on publication rather than being based on accuracy and sense (Dusch, 1994; Viennot, 1985). However, in our revision, we have noticed a general effort to look for coherence in the data, to obtain as much information from the student as possible, to look for a large number of regularities, etc. Therefore, we do not believe researchers deliberately overlook "weaknesses" in their studies, but rather that, they have not properly focused on the problem, because the theoretical context is not the most suitable or the methodological tools are inadequate. We think there is a hidden problem in the conceptions research line which, despite its delicate nature, should be explained: it is not sufficient to study the problem of conceptions armed only with one's own disciplinary background because research into conceptions is a problem related to the student's knowledge and not to the narrow scientific training of the researcher. Indeed, the training might well act as a "*epistemical barrier*" against the researcher him/herself.

Other studies on the same topics, more rigorous and better founded (e.g. Piaget, 1975; Inhelder and Piaget, 1972; Piaget, 1946), and even our researches (Marín, 1994b; Benarroch, 1998), show that there is "*more to say*" about students' knowledge than that which is reflected in some studies on conceptions, which undervalue other theoretical tendencies or theoretical contexts.

In short, any investment in the conceptions research line is a high cost study and any return, outside the merely personal, will only come when we see that the results are applicable to the classroom.

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