It is so difficult to find the beginning. Or, better; it is difficult to begin at the beginning. And not to try to go further back.

(Wittgenstein, 1977, p. 471)

1.1.0. Introduction

In this section there is a brief introduction to research in children's ideas in science. Constructivism is examined as a theoretical perspective which has influenced the research in the field of science education. A constructivist view of learning is also presented with a focus on learning as conceptual change.

1.1.1. Research into children's ideas in science

During the last twenty-five years or so, there has been a boom in research on the role of children's ideas in teaching and learning of science. Bibliographies provide overviews on the range and amount of work done. Pfundt and Duit's bibliography (1994) or Driver and Watts' (1990), which are both continually updated, contain more than 2500 entries of research papers in the field. There are also several reviews in the field which ease the access to many research papers and highlight common points of departure (for example, Driver & Easley, 1978; Driver & Erickson, 1983; Gilbert & Watts, 1983; Hashwesh, 1986; Duit, 1991; Fensham, Gunstone & White, 1994).

At the outset, in the mid 1970's, the emphasis was on investigating learner's conceptions on science topics such as heat, light, energy, force, chemical reactions, photosynthesis, genetics etc. Quite often, this research also looked for conceptual change during, mostly traditional, teaching interventions. However, studies on the effects of teaching interventions that aimed to bring about conceptual change followed a little later (cf. § 1.3.1). Nevertheless, a basic assumption for all this research work is that the conceptions that learners hold prior to teaching interventions guide their learning considerably.

The researchers dealing with learner's ideas or conceptions are by no means a homogenous group. This is proved by the plethora of terms, and their underlying, theoretical and epistemological assumptions, which are used to describe children's conceptions (for example, see Ambibola, 1988). Thus, terms like *alternative frameworks* (Driver & Easley, 1978; Watts, 1983a) *conceptual frameworks* (Driver & Erickson, 1983; Engel-Clough & Driver, 1986), *alternative conceptions* (Osborne & Gilbert, 1980b) *children's ideas* (Driver et al., 1985) *preconceptions* (Ausubel, 1968) *misconceptions* (Helm, 1980; Hills, 1989), *children's science* (Gilbert, Osborne & Fensham, 1982), *minitheories* (Claxton, 1993) or *mental models* (Vosniadou, 1991; 1994) have been used to express children's informal, untutored or intuitive ideas in science. All of these terms have specific meanings within broader theoretical contexts. For example, the term *alternative frameworks,* which is a widely used term in the field of research in science education, indicates that learners conceptions are not a miscellaneous collection of "fuzzy" ideas, but are surprisingly coherent, organised in explanatory frameworks. These frameworks appear to be alternatives to the science taught in schools and they tend to provide the learners with valuable guidance in most everyday situations. However, the use of the word *alternative* may be taken to imply that the learners' ideas need to be described and explored in the learners' *"own terms, so that we may come to appreciate their conceptual schemes from the inside"* (Hills, 1988, p. 167). Gilbert and Swift (1985) have termed this field of research as the *alternative conceptions movement* (ACM).

The idea of investigating children's conceptions in science in a rather old one. Even from the early '30s, Piaget used his research method of *clinical interview* to investigate "the child's conception of ..." "the world" (1929), "physical causality" (1969), "movement and speed" (1970) and presented a plethora of children's intuitive ideas in many science topics. Furthermore, the idea that these intuitive conceptions play an important role in the teaching and learning of science seems to be an old one as well. Bachelard's (1938) work relates science education and the epistemology of science and he points out that:

> I have often been puzzled by the fact that science teachers even more than other teachers -if possible- fail to understand why students do not understand the material taught. Very few are those who have delved into the psychology of error, of ignorance and thoughtlessness ... They have not yet reflected on the fact that the adolescent enters the physics class with pre-conceived ideas: the central problem of students is not to *acquire* an experimental culture but rather to *change* their experimental culture, to demolish the obstacles accumulated by daily experience (Bachelard, 1938, p. 18; as quoted in Souque, 1988).

Bachelard (1938) refers to *epistemological obstacles* that learners have to confront in the learning of science, such as immediate experience, obstacles that deal with the use of language, animism etc. (Souque, 1988).

Children acquire alternative conceptions from various sources. Everyday experiences involving sensual impressions encountered in natural phenomena such as heat, sound, light, force, motion and many others, are undoubtedly a major source of alternative conceptions (for example, Viennot, 1979). In everyday communication and interaction with friends parents and others, learners pick up both pieces of scientific knowledge and alternative conceptions (Solomon, 1987). Further sources of information such as mass-media, also provide science knowledge that is not always "correct" from the science point of view. Everyday language also appears to be a major source of science conceptions (Gilbert, et al. 1982; Sutton, 1980; 1992). An interesting view is that of Preece (1984), who introduced the idea that student's conceptions may be *triggered* by innate structures of the brain and that they are not (merely) learned. Quite often, teaching interventions may support children's intuitive beliefs or generate new "misconceptions", which may be created due to false information provided by the teacher (or the textbook) or misinterpretation of basically correct information (Hills, 1989).

There has been a continuing debate on whether children's alternative conceptions in science are *coherent* and organised in explanatory frameworks, or *fragmental,* without the powerful links of a theoretical framework. Thus, Watts & Gilbert (1983) for example, referring to the status of children's conceptions explain that:

> Such views of the world, beliefs and meanings for words are not simply isolated ideas, but rather they are part of the complex structures which provide a sensible and coherent understanding of the world from the youngster's point of view.

Driver (1990), appears to be more sceptical and argues that these conceptions seem to be coherent within limited contexts. She mentions, for example, that the "motion-implies-force" conception seems to be used consistently by children in the context of friction. On the other hand, diSessa (1988) proposes that the intuitive knowledge about the world is "knowledge in pieces", emphasising its fragmental nature. He points out that children's ideas in science consist of "a large number of fragments rather than one, or even a small number of integrated structures one might call theories" (ibid.). In this respect, scientific learning involves the organisation of these fragments.

1.1.2. Theoretical background of research into children's ideas: a constructivist view of learning.

Constructivism appears to be the most profound theoretical basis for research into children's ideas in science and conceptual change. Solomon (1992) suggests that "the nearest the research community has come to a common perspective is through the use of the term *constructivism*" (p. 37). However, constructivism appears to be a heterogeneous movement. A recent review has identified the following varieties: dialectical, contextual, empirical, information-processing, methodological, moderate, Piagetian, postepistemological, pragmatic, radical, realist, social and sociohistorical (Good, Wandersee & St. Julien, 1993). Constructivists draw on different theorists to base their assumptions. As Watts (1994) contends constructivism encompasses *"writers of Ausubelian, early-Piagetian, Kellyian and Vygotskyian persuasion (to note just a few)"* (p. 51). A common point of view appears to be that learning is an interpretative process, which involves individual's constructions of meaning relating to specific occurrences and phenomena. New constructions are built through their relation to prior knowledge (ibid.). This means that people are active rather than passive learners. As Mahoney (1988) points out:

> Constructivism refers to a family of theories that share the assertion that human knowledge and experience entail the (pro)active participation of the individual.

Kelly (1955), with his theory of *Personal Constructs*, has been very influential for science education researchers. He takes a root metaphor, that of *man-the-scientist* and suggests that in the course of everyday life, people act like scientists. The Kellyian scientist is a constructivist (Pope & Gilbert, 1983). Kelly described his epistemological position as *constructive alternativism*, suggesting that people understand themselves, their surroundings and anticipate future eventualities by constructing tentative models and evaluating them against personal criteria (ibid.). He pointed out that *"the open question for man is not whether reality exists or not, but what he can make of it "* (Kelly, 1969, p. 25). Kelly rejected the absolutist view of truth, contrasting his position of *constructive alternativism* with *accumulative fragmentalism* - the notion that knowledge is a growing collection of substantiated facts or "nuggets of truth", independent of human reconstruction. On the contrary, he proposed that even the most highly developed scientific knowledge can be seen as subject to human reconstruction. These constructs are man-made hypotheses which a person may choose to bring under review and revise them in the light of what might appear to be a more persuasive or a "better" theory. This philosophical position has striking resemblance to the philosophies of science which developed in the sixties and seventies. Kuhn's (1970) paradigm shifts, Lakatos' (1970) research programmes, Popper's (1963) identification of the theory-laden basis of science, Polanyi's (1958) notions of personal knowledge, Toulmin's (1972) notion of conceptual ecology and the evolutionary nature of science, Feyerabend's (1975) epistemological anarchism, all adopt the perspective of a continuous reconstruction of scientific explanation. Moreover, they point out the conjectural and provisional nature of science. Such an approach is antithetical to the search for laws of human nature, which has, in the past, dominated psychological and educational research (Pope & Gilbert, 1990).

A key assumption within Kelly's theory is the *individuality corollary*, stating that "persons differ from each other in their construction of events". He emphasised the uniqueness of each person's construct system and the importance of the expression of these constructs, in order to achieve communication and exchange. For Kelly learning is a personal exploration and in this sense, teachers "must come to some understanding of the experiments, lines of enquiry and personal strategies used by the learner" (Pope & Watts, 1988, p.103). Kelly (1970) saw the teacher's role as helping:

> ... to design and implement each child's own undertakings, as well as to assist in interpreting the outcomes and in devising more cogent behavioural inquiries. But usually she has to begin as any apprentice begins, implementing what others have designed; in this case what her children have initiated. To be a fully accredited participant in the experimental enterprise **she must gain some sense of what is seen through the children's eyes** (p. 262, emphasis added).

The metaphor *child as a scientist* has emerged from Kelly's *man-the-scientist* and it is used to describe children working like scientists in their endeavour to make sense of natural phenomena either in the classroom or outside it (Gauld, 1988). The learner is to be at the very centre of the learning experience and the whole process of teaching and learning is to be child-oriented (Bentley & Watts, 1994).

Driver (1988) lists six features of a constructivist perspective, which are considered to have an impact in the process of teaching and learning:

- Learners are not viewed as passive but are seen as purposive and ultimately responsible for their learning. They bring their prior conceptions to learning situations.
- Learning is considered to involve an active process on the part of the learner. It involves the construction of meaning and often takes place through interpersonal negotiation.
- Knowledge is not 'out there' but it is personally and socially constructed, its status is problematic. It may be evaluated by the individual in terms of the extent to which it 'fits' with their experience and is coherent with other aspects of their knowledge.
- Teachers also bring their prior conceptions to learning situations not only in terms of their subject knowledge but also their views of teaching and learning. These can influence their way of interacting in classrooms.
- Teaching is not the transmission of knowledge but involves the organisation of situations in the classroom and the design of tasks in a way which promotes scientific learning.
- The curriculum is not that which has to be learned, but a programme of learning tasks, materials and resources from which students construct their knowledge. (p. 138)

So far it could be argued that constructivism places emphasis on the individual's construction of meanings. However, this does not mean that it ignores the influences from the social environment in the construction of these meanings. Learning is not context free. On the contrary, it is embedded in a social and cultural context. As Watts (1994) points out, constructivism "implies a social context where ideas and conceptions are communicated, shared, tested, negotiated and reported". Hence, the learner is constructing knowledge that is part of the socially constructed and consensually agreed knowledge of the community of scientists. As Driver (1989) puts it,

> Learning science, therefore, is seen to involve more than the individual making sense of his or her personal experiences but also being initiated into the 'ways of seeing' which have been established and found to be fruitful by the scientific community. Such 'ways of seeing' cannot be discovered by the learner - and if a learner happens upon the consensual viewpoint of the scientific community he or she would be unaware of the status of the idea (p. 482).

Language plays an important role in communication and in the social construction of knowledge or the shaping of thinking (Driver, 1989). Vygotsky (1962) regards word-meanings as phenomena of thinking, dynamic formulations which evolve and change as the child develops. In this sense, words are not merely used to express thought, they are the means by which thought comes to existence (Bentley & Watts, 1992).

1.1.3. Learning as a process of conceptual change

Research into children's ideas has provided a relatively extensive catalogue of alternative conceptions in almost all science topics. It is quite clear that learners have a number of unorthodox ideas about natural phenomena, which they bring to science classrooms and most of the times they remain intact in the face of normal everyday teaching. At this point, Watts (1991) poses a question, which has been very influential and inspiring in the course of this inquiry, "what do we *do* once we know" about these alternative conceptions, and most importantly "can they be changed and, if so, how best can we organise that?" (p. 55). In the last fifteen years or so, there seems to be a focus on learning as a process of conceptual change. Educationalists are working on the organisation of methods, teaching materials and learning environments, in order to facilitate and promote conceptual change (cf. § 1.2.1. & § 1.3.1).

Driver (1984) referring to the process of learning as conceptual change, seen from the point of view of the learner, mentions that:

> Conceptual change involves the learner actively constructing his or her own meaning in any situation whether it is text, dialogue or physical experience.

In broader terms, learning as a process of conceptual change "is commonly portrayed as taking place from personal intuitive knowledge to 'correct' (scientific) knowledge" (Watts, 1992, p. 124). West and Pines (1985) suggest that there are two sources of knowledge for the learner. One is the knowledge that learners acquire from interaction with the environment and it is termed as *intuitive* or *naive* knowledge. Its primary characteristic is that it constitutes the person's reality, something the person believes in. The other source of knowledge is that coming from formal teaching, or in other words, the school knowledge, which is someone else's interpretation of the world, someone else's reality. Its primary characteristic is authority. In this respect, learning can be viewed as the process in which learners make their own sense of these two inputs. West and Pines (1985) point out that "learning always involves the interaction between the learner's present understanding of the world and the knowledge input" (p. 3). They go further to describe their view of learning as conceptual change by using a metaphor of two vines growing in opposite directions as follows:

> We imagine two vines representing these two different sources of knowledge, the one originating from the learner's intuitive knowledge of the world (which we call the upward-growing vine to emphasise that this is part of the growth of the learner) the other originating from formal instruction (which we call the downward-growing vine to emphasise its imposition on the learner from above. Genuine conceptual learning involves the intertwining of these two vines (West & Pines, 1985, p. 3).

These two vines can be in a *conflict situation* when the learner's reality is in conflict with the principles being presented; in a *congruent situation,* when both vines are well established, but not in conflict; in a *symbolic situation*, when there is hardly any upward vine to interact with the school knowledge; or in an *uninstructed situation*, when there is little or no formal schooling and all the learner's knowledge is based on intuitive learning (ibid.). West and Pines (1985) describe three forms of conceptual learning. They refer to *conceptual development*, as the gradual expansion, increasing intertwining or integration and development of the learner's conceptions; to *conceptual resolution* as the acceptance of the congruence, or the resolution of a conflict, between the learner's and science conceptions; and to *conceptual (ex)change* as a resolution of a major conflict, such as the replacement of a learner's conception with a "correct", scientific one. They claim that the latter form of conceptual learning, conceptual change, involves abandoning a learner's commitment to one set of conceptual understandings by adopting another irreconcilable one. This abandonment is not always a component of conceptual learning, or an everyday classroom phenomenon, but when it happens it appears to be a "difficult and painful process which requires both a commitment on the part of the learner and special instructional techniques" (West and Pines, 1985, p. 7).

In the following two sections, some theoretical approaches on teaching and learning science with a focus on conceptual change are presented and analysed.

1.2.0. Introduction

In this section some of the theoretical approaches that refer to the construct of *conceptual change* have been selected and the basic characteristics of each of these approaches are presented and analysed. In most cases, relevant points of critique are also discussed. These theoretical approaches appear to have some common points of departure, which can be classified in two different groups, which are presented and discussed at the end of this section.

1.2.1. Some theories of conceptual change

Posner et al. (1982) have drawn upon accounts of scientific theory change given by Kuhn (1970), Lakatos (1970) and Toulmin (1972) in order to constitute an analogy between the conceptual change in the scientific disciplines and the conceptual change in people learning science. The main question which Posner et al. (1982) attempt to answer is: *"How do learners make a transition from one conception C_1 to a successor conception C_2"* (Strike & Posner, 1992). They claim that they have used the term *conception* to mark the plurality and internal complexity of these "objects of change" and to distinguish it from the term *concept* which is used in normal discourse. The theoretical perspective that they developed was meant to apply to concepts that play a central, generative or organising role in thought. Hence, they were interested in a phenomenon analogous to Kuhn's notion of a *paradigm shift* (Kuhn 1970)[1] or Piaget's notion of an *accommodation* (Piaget, 1950). In this sense, a learner who is able to replace an Aristotelian or Newtonian view of motion with Einstein's has undergone the kind of "radical" conceptual change that Strike et al. (1982) have considered. They do not claim that all learning involves this form of conceptual change (Strike & Posner, 1992). On the contrary, although they point out that most cases of "altered belief", or cases of *assimilation*, do not count for their

[1] cf. relevant points of discussion in the theoretical approaches of Carey (1985) and Vosniadou & Brewer (1987) that follow.

theoretical perspective, they appear to accept that there are cases of learning in which central concepts are not at issue (cf. Peter Hewson's (1981) notion of *conceptual capture* that follows)

There seem to be four conditions necessary for successful conceptual change to occur, as it is suggested in the literature of philosophy of science (Posner et al., 1982, p. 214; Strike & Posner, 1985, p. 216; Strike & Posner, 1992, p. 149).

1. ***There must be a dissatisfaction with existing conceptions.*** Scientists and learners are unlikely to make major conceptual changes until they believe that less radical changes will not work. People do not accommodate while assimilation is still reasonable. Their concepts must be in Kuhn's (1970) words "awash in a sea of anomalies".
2. ***A new conception must be intelligible*** (minimally understood). Learners must be able to grasp how experience can be structured by a new conception to explore the possibilities inherent in it. One of the difficulties to overcome in bringing off a dramatic conceptual change is that the new conception is often not only counterintuitive, but incomprehensible (see Strike & Posner, 1985) to those committed to the old conception. Writers often stress the importance of analogies and metaphors in lending initial meaning and intelligibility to new concepts (for example, Vosniadou & Ortony, 1989).
3. ***The new conception must appear initially plausible***. Any new conception adopted must at least appear to have the capacity to solve the problems generated by its predecessors and to fit with other knowledge, experience, and help. Otherwise it will not appear a plausible choice. Plausibility is also a result of consistency of concepts with other knowledge. To be a candidate for adoption, a new conception need not be seen as true, but it must at least appear as a candidate for the truth.
4. ***A new conception should suggest the possibility of a fruitful research programme.*** It should have the potential to be extended to open up new areas of inquiry, to be a productive tool of thought and to have a technological and explanatory power.

Swift (1984)[2] has schematised these four conditions of conceptual change, bearing in mind Hewson's (1981) contribution to this theoretical perspective, by using his notion of *conceptual exchange* (cf. respective analysis that follows) to refer to Posner's et al. (1982) notion of *accommodation* or radical conceptual change (see fig. 1.2.1.).

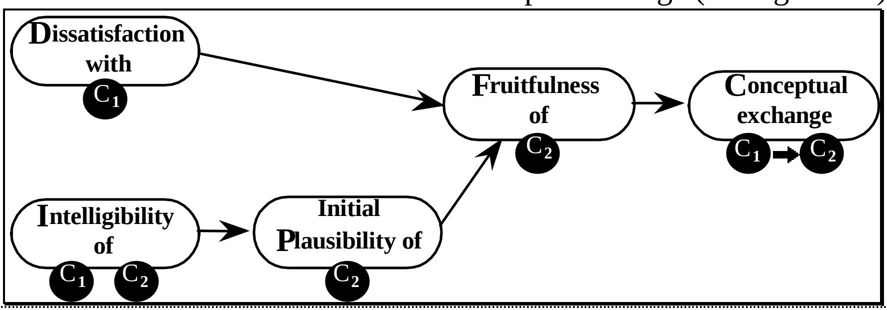

Fig. 1.2.1: Swift's (1984) schematic representation of the four conditions of conceptual change as they have been expressed by Posner et al. (1982) in combination with Hewson's (1981) notion of *conceptual exchange*.

[2] As quoted in Watts (1992, p. 35).

With the four conditions presented above, it is assumed that learning takes place in a conceptual context, which means that old conceptions and candidates for their replacement are understood and appraised by learners in terms of concepts they already posses. Posner et al. (1982) have borrowed an environmental concept from Toulmin (1972) to label this conceptual context, calling it a *conceptual ecology*. Thus, not only it is assumed that there is a conceptual ecology for the preceding conditions of conceptual change to emerge, but also some clues as to its composition are provided. It is suggested that a conceptual ecology consists of such *cognitive artifacts* as anomalies, analogies, metaphors, epistemological beliefs, metaphysical beliefs, knowledge from other areas of inquiry and knowledge of competing conceptions (Posner et al., 1982; Strike & Posner, 1985; Strike & Posner, 1992). It has been claimed that these aspects of conceptual ecology are pedagogically interesting in two respects: (a) they provide an inventory of the kinds of cognitive artifacts that learners are likely to posses, which must be taken into account in a teaching and learning process. Moreover, they should also be seen as assets or libraries of conceptions that may promote or frustrate progressive conceptual change, and (b) they suggest the kind of things that should be provided in a teaching and learning process in order to facilitate conceptual change (Strike & Posner, 1992). In an attempt to broaden the context of their theoretical perspective, they have pushed their argument a bit further by claiming that conceptual change theory *"can be stated in a more general form by emphasising that what it centrally requires is a focus on the learner's conceptual ecology and how that ecology structures learning"* (Strike & Posner, 1992, p. 159). Nevertheless, Posner and Strike (1992) admit that by describing this view of conceptual change they did not suppose that they were presenting a *"detailed account of learning that could be immediately applied to the classroom"* (p. 150).

Although Posner's et al. (1982) theory has been very influential in science education it has also received several points of critique which could be summarised in the following three:

- The theory was based on the assumption that learners have well-articulated conceptions or misconceptions about most topics.
- The theory was too linear.
- The theory was overly rational. (Strike & Posner, 1992)

Strike and Posner (1992), in retrospect, describe their original conceptual change theory as "largely an epistemological theory, not a psychological theory ... it is rooted in a conception of the kinds of things that count as *good* reasons" (Strike & Posner, 1992, p. 150, emphasis in the original). Their original work is concerned with the "formation of rational belief" (p. 152); it does not "describe the typical workings of students minds or any laws of learning" (p. 155). Nevertheless, they mention that:

> We have always regarded attempts to turn our four components of conceptual change into four steps of instruction as misinterpretations of our intent (Strike & Posner, 1992, p. 172).

Thus, they seem to acknowledge that the move from normative theory (which is what they claim their theory to be) to classroom practice is not direct. Furthermore, their critics have argued that the process of change may not be necessarily seen as linear or abrupt, but, on the contrary, for some learners, it may be *"a gradual and piecemeal affair"* (Watts & Bentley, 1987, p. 125). It has also been argued that *"nonrational components are intrinsic to conceptual change in the individual, and that these should not be excluded in the investigations of conceptual change"* (West & Pines, 1983, p. 37). West and Pines (1983) listed power, simplicity in complexity, aesthetics, and personal integrity as potentially significant nonrational components of conceptual change.

A few more points of critique are expressed by Clark (1985)[3] who contends that:

> The theory of conceptual change (as articulated by Posner, Strike et al.) hold that the state of *readiness* for conceptual change ought best to arise from the learner's own attempts to make sense of experience ... Yet a troublesome aspect of the way in which their work has been transformed into an instructional method is that the topics addressed arise from the wisdom of the curricularist, not the curiosity of the learner. The teacher is asked to *rush students to readiness* by posing a question ... that probably never occurred to the students, and then induce dissatisfaction with their own explanations by confrontation ... The result is a kind of 'cognitive assault' in

[3] As quoted in Watts (1992, p. 36).

> which students are *forced* to confront and abandon a part of self that has been, and is, serving them reasonably well..

Apart from this influential, strongly criticised and rather classic theoretical approach on conceptual change, several others have been developed. Some of them are briefly presented below.

Thagard (1992, p. 35) analyses conceptual change in science and claims that there are nine degrees of change, which could, as well, be applied to conceptual change in children (p. 259): (1) adding a new instance, (2) adding a weak rule, (3) adding a new strong rule, (4) adding a new part-relation, (5) adding a new-kind relation, (6) adding a new concept, (7) collapsing part of a kind hierarchy, (8) branch jumping and (9) tree switching. Thagard (1992) distinguishes between conceptual change and belief revision, in which relations between concepts and are established or rejected without deeply affecting the concepts. Hence, belief revision involves either addition or deletion of beliefs, whereas conceptual change comes in varying degrees:

- *additions of concepts*;
- *deletion of concepts*;
- *simple reorganisation,* in the kind hierarchy or part-hierarchy, in which new kind-relations or part-relations are established;
- *revisionary reorganisation* in the hierarchies, in which old kind-relations or part-relations are replaced by different ones; and
- *hierarchy reinterpretation*, in which the nature of the kind-relation or part-relation that constitutes a hierarchy changes. (Thagard, 1992, p. 252)

The first three kinds of conceptual change could be seen as instances of revising one's beliefs, whereas the last six refer more to the "conceptual structure", especially the last two, "branch jumping" and "tree switching".

Carey (1991) defines concepts as "structured mental representations" (p. 258) and suggests that conceptual change may occur within three possible ways: a concept that is periphery becomes core and vice versa, concepts are subsumed into a new category, or concepts are embedded in logically incommensurable theories. She highlights the difference between conceptual change involving these three types of change with *weak restructuring* or enrichment that occurs when new knowledge about entities is acquired or new beliefs are represented. On the other hand, *strong restructuring* involves in addition a change in ontological commitments. Thus, it seems that for Carey, conceptual change involves by definition, strong restructuring.

In an earlier study, Carey (1985) suggests that children undergo conceptual change analogous to radical kinds of conceptual changes described by historians of science such as Kuhn (1970). She presents "paradigm cases" of conceptual change which are the coalescence and differentiations (weak restructuring), or the alterations in ontological commitments (strong restructuring) that occur in scientific transitions as the one from Aristotle to Galileo. Carey (1985) contends that the acquisition of biological knowledge by children between the ages of 4 to 10 likely involves theory change similar to that found in science. Thus, she says that children shift from an animist theory, in which the sun and the trees are considered as alive, to a set of biological theories explaining facts that the animist theory would explain only in terms of intentional activity. For example, a very young child may consider the sun as alive because it gives light or may contend that trees got the idea of blooming form other trees, but by the age of 10 children have acquired enough biological knowledge to reject their old beliefs (ibid.). Hence, ten-year olds appear to understand gender, reproduction, digestion, circulation, respiration and death in terms of internal bodily processes. It seems that Carey's most plausible case for conceptual change concerns the concept of *living thing*. Children appear to distinguish between *alive* and *dead* but not between *alive* and *inanimate*. Whereas 10-year olds appear to be able to class animals and plants as alive, in distinction from inanimate objects, younger children's categories are much more confused or blurred (ibid.). Thus, part of the knowledge reorganisation that occurs as children acquire more biological knowledge is the coalescence of *animal* and *plant* into the superordinate concept of *living thing*. This development is compared to Galileo's collapse of Aristotle's distinction of *natural* and *violent* motion (ibid.).

Peter Hewson's (1981) initial formulation of the conceptual change model of science learning, later developed by Posner et al. (1982), also quotes Kuhn and Lakatos on the conditions of theory change and, following the latter, reports that *"some of the most important conceptions influencing conceptual change in an individual were found to be ... the metaphysical [and epistemological] commitments which he or she held"* (Hewson, 1982, p. 131). Two major components of this model of conceptual change are the *"conditions that need to be satisfied in order for a person to experience conceptual change and the person's conceptual ecology that provides the context in which the conceptual change occurs and has meaning"* (Hewson & Thorley, 1989, p. 541) (cf. preceding analysis on the theoretical approach of Posner et al., 1982).

Hewson & Thorley (1989) and Hewson & Hewson (1992) contend that when a learner considers a new conception three possibilities, or three varieties may exist. In one variety the former understanding or conception is extinguished and is replaced by a new one, much like the fairy tale where the princess kisses a frog, which changes into a prince. In other words, a new conception is accepted by lowering the status of a former (and conflicting) conception and by raising the status of a new conception in a process called *accommodation* (Posner et al., 1982) or *conceptual exchange* (Hewson, 1981) (also Hewson & Thorley, 1989; Hewson & Hewson, 1992). In the second variety the change involves adding to or deleting from an existing conceptual structure which appears to be similar to the case of a savings account. It refers to a type of change that involves children's learning about *"things they didn't know by making connections to what they already know"* (Hewson & Hewson, 1992, p. 61). This process is called *assimilation* (Posner et al., 1982) or *conceptual capture* (Hewson, 1981) (also Hewson & Thorley, 1989; Hewson & Hewson, 1992). In the third variety one alternative conception is preferred over the other. Hewson & Hewson (1992) use the analogy of election to a political office in which one out of two candidates becomes a mayor, but both people continue to live in the same town. They appear to believe that most changes in learners' conceptions resemble to the latter type, in which the learner still remembers the earlier conception. Hewson &

Hewson (1992) point out that in common practice, a "radical" form of conceptual change (accommodation) *"refers only to instances of conceptual exchange"* (p. 62), which do not appear to be frequent in the everyday teaching and learning of science.

Dykstra et al. (1992) rely on Piaget's constructs of assimilation, accommodation and disequilibration without appealing to Piaget's stages of cognitive development. An assimilation of concepts involves the strengthening of existing beliefs, whereas accommodation involves a change in the belief about how the world works. Hence they contend that *"the point of instruction should be to induce conceptual change. It cannot accomplish this without using disequilibration"* (p. 626). They clarify that disequilibration is *not* a contradiction, for the former refers to "conceptual incongruity", whereas the latter involves "logical inconsistency". They suggest that the majority of "conceptual changes" are members of three categories described as:

- *Differentiation*, wherein new concepts emerge from existing, more general concepts, for example, velocity and acceleration emerging from generic ideas of motion in kinematics
- *Class extension,* wherein existing concepts considered different are found to be cases of one subsuming concept, for example, rest and constant velocity coming to be viewed as equivalent from the Newtonian point-of-view.
- *Reconceptualisation*, wherein a significant change in the nature of the relationship between concepts occurs, for example, in the change from "force *implies* motion" to "force *implies* acceleration", much like Carey's strong sense of restructuring. (Dykstra et al., 1992, p. 637)

Chi (1992) distinguishes between two types of conceptual change: *radical* and *normal*. At the basis of this distinction is the locale of conceptual change in relation to three ontological categories, *matter, events,* and *abstractions* (Chi, 1992), or *matter* (things), *processes* and *mental states* (Chi et al. 1994). Misconceptions arise because learners assign science concepts to an ontological category to which they do not belong. For example, learners may assign the concept of heat to the ontological category *matter*, when, in fact it belongs to the ontological category *process* (Chi et al., 1994). Conceptual change occurs when a concept is reassigned from one category to another. Thus, reorganisational shifts within these categories constitute *normal* conceptual change, whereas shifting across categories constitutes *radical* conceptual change. The ontological status of the initial and scientific conceptions determines the difficulty of learning. If the two conceptions are ontologically compatible (e.g., both are matter) conceptual change is easy. If the two conceptions are ontologically distinct, learning is difficult. Chi (1992) suggests that radical conceptual change involves reassigning the ontological status of a concept which could be categorised as an *event*, *abstraction* or *matter*. She points out that *"whether or not misconceptions are robust, consistent or theory-like depends on whether an ontological shift is necessary in their removal"* (Chi, 1992, p. 184). Hence, for example learners' "naive conceptions" about force, light, heat and current, which are seen as kinds of *matter,* should be reconceptualised as fields, which she describes as belonging to a different ontological category. Nevertheless, Chi (1992) argues that when children learn theories in physics, they never abandon their old naive theories, but continue to use them in everyday life.

Vosniadou and Brewer (1987, 1990) have investigated the development of children's knowledge in astronomy. They describe, for example, how children who are routinely told that the earth is round, have difficulties in reconciling this claim with their intuitive beliefs and observations. They claim that most of the children at the end of primary school appear to be holding a conception that the earth is a sphere, whereas younger children appear to be holding different intuitive views about the earth being flat or having the shape of a disk. These beliefs are mostly based on their phenomenal experience of everyday life and their observations, which contradict with what the parents and the teachers are telling them about the earth being round. Thus, children develop models that reconcile these two beliefs, like a *dual earth* model in which they believe that there are "two earths": one on which people live and a round one which is up in the sky. Some children believe that the earth consists of two hemispheres: a lower one on which people live and an upper one that has the sky, covering the lower one like a dome. On this view, the earth looks like a *hollow sphere* and we live inside it, not on top of it (see also Vosniadou, 1991).

Vosniadou (1991; 1992; 1994) has adopted the construct of *mental models* to characterise these mental representations that individuals form. She contends that *"mental models are dynamic and generative representations which can be manipulated mentally to provide causal explanations of physical phenomena and make predictions about the state of affairs in the physical world"* (Vosniadou, 1994, p. 48). Vosniadou (1991) claims that these mental models can be grouped in three distinct categories:

- *intuitive models*, which require as little deviation as possible from the natural world as it is phenomenally experienced. They don't show any influence from adult scientific models. An example of an intuitive model can be that of a flat or disk-shaped earth.

- *scientific models* are models held by most adults in our society, the models that agree with the current scientific views.

- *synthetic models*, show a combination of intuitive and scientific views such as the earth being a hollow sphere. Synthetic models are similar to what other researchers have called *misconceptions* since they represent some kind of misinterpretation of scientific information. Children appear to be constructing synthetic models in their attempt to interpret counter-intuitive information in a way that does not contradict their entrenched beliefs. (Vosniadou, 1991, p. 225)

Vosniadou and Brewer (1987) point out that the process of knowledge acquisition can be conceptualised as involving different kinds of changes, since some require the *enrichment* or articulation of an existing conceptual structure and others the creation or *revision* of new structures (also Vosniadou, 1992; 1994). *Enrichment* is conceptualised as the simple addition of new information to an existing theoretical framework through the mechanism of accretion and it is assumed to constitute a relatively easy form of conceptual change. On the other hand, *revision* is required when the information to be acquired is inconsistent with existing beliefs or presuppositions, or with the relational structure of a theory (Vosniadou, 1994). It is argued that the revision of a specific theory (e.g. the moon has water and oxygen) is easier than the revision of a framework theory (the earth is flat as it is phenomenally and intuitively experienced, on a basis of ontological presuppositions). Vosniadou (1994) suggests that *"the change of a framework theory is difficult because the presuppositions of the framework theory represent relatively coherent systems of explanation, based on everyday experience and tied to years of confirmation"* (p. 49).

Vosniadou and Brewer (1987) contend that current discussions of the notion of restructuring in knowledge acquisition differentiate between *weak* and *radical* restructuring. The first involves the accumulation of new facts and the formation of new relations between existing concepts, whereas the latter involves a fundamental change in schemata or core concepts, in the structure and/or the phenomena to be explained, similar to paradigm shifts in the history of science (Hanson, 1958; Kuhn, 1970). They claim that the knowledge restructuring view raises important questions about the similarities and differences in the child's and scientist's acquisition of knowledge and about the role of prior knowledge in the process of teaching and learning. Hence they suggest that one possible way to conceptualise the distinction between weak and radical restructuring is to view it as analogous to the distinction between theory change and change in paradigms in the history of science (Kuhn, 1970) (cf. Posner et al., 1982; Strike & Posner, 1992).

According to Kuhn the exercise of "normal science" involves the articulation of an existing paradigm that may result in theory change. Only when these attempts at articulation fail repeatedly does the motivation of a paradigm shift arise and this is a period of "extraordinary science" leading to a "crisis" and a "scientific revolution". Paradigm shifts happen in an effort to resolve "anomalies" that exist in the relation of existing theory to observations (Kuhn, 1970, p. 97). It is clamed that the development of knowledge in the child can be seen in similar terms, as a process of enriching and elaborating existing ideas or "theories" that can give rise to theory change, or in other words to weak restructuring. Only occasionally when the child is faced with major anomalies the existing conceptual structures cannot account for, a new "paradigm" is required, giving rise to radical restructuring. One needs to be careful in the interpretation of such an analogy, since there are important differences between children and scientists that need to be considered. Unlike the scientists, children do not necessarily require an internally consistent new paradigm, which can be independently discovered (Kuhn, 1970). On the contrary, children need to integrate current scientific views (coming from the adult world) with theories and opinions deriving from their phenomenal experience, which may lead to synthetic models of interpretation in an attempt to reconcile contradicting views, or conflicting pieces of evidence (Vosniadou & Brewer, 1987).

Vosniadou (1992) points out that in order for radical change to occur, learners must learn to question their intuitive beliefs and to replace them with a new explanatory framework. She also suggests that an effective teaching and learning process should create certain circumstances for learners to *"become aware of the theoretical nature of their intuitive constructions, and of the need to replace them with explanations that are more adequate to explain the relevant empirical observations"* (Vosniadou, 1992, p. 356).

Thagard (1992)	**Carey (1991)**	**Chi (1992)**	**Dykstra et al. (1992)**	**Hewson & Hewson(1992)**	**Vosniadou (1992;1994)**
Add instance Add weak rule Add strong rule			Differentiation		
Add part relation Add kind relation Add new concept	Weak restructuring	Normal conceptual change	Class extension	Conceptual capture	Weak restructuring (*enrichment*)
Collapse kind hierarchy Branch jumping Tree switching	Strong restructuring	Radical conceptual change	Reconcep-tualisation	Conceptual exchange/ replacement	Radical Restructuring (*revision*)

Table 1.2.1: A tabular representation of some theories of conceptual change presented above.

It could be argued that all of the theoretical approaches which are briefly presented above (see also Table 1.2.1) have common points of departure in the way that they depict "conceptions" and "conceptual change". Common points of departure may still exist despite the implicit, and sometimes explicit differences reflecting underlying epistemological variations framing the various studies. Although it has been argued that the notion of "conception" is seldom made explicit in the literature (Nussbaum, 1989), it seems that for the preceding theoretical approaches conceptions are depicted as tangible *inside-head* constructs made up of structured propositional patterns of reasoning (Novak & Gowin, 1984; White and Gunstone 1989). Thus, in a broader context, conceptual change appears to be achieved in three ways: (a) acquisition of new information (adding to the internal structure), (b) reorganising existing knowledge (reorganising the internal structure), and (c) no longer viewing some attribute of the structure as worthwhile knowledge (discarding some of the internal structure). In other words, it is considered that conceptual change takes place within a person's head (for example, see Posner, et al. 1982; Hewson 1981). It could also be argued that the notion of "conceptualisation stability" is implicit in the notion of conceptual change as it is viewed in the preceding studies. This theoretical perspective could be labelled as *mental model*-based perspective (Linder, 1993) or as a constructivist framework of ideas (Marton & Neuman, 1988).

On the other hand, there is another theoretical perspective which could be labelled as an *experientially* based perspective (Linder, 1993), or a constitutionalist framework of ideas (Marton & Neuman, 1988). The experiential perspective has been developed by *phenomenography* researchers at the Gothenburg University (see for example Marton 1981a; 1981b; 1986; Johansson, et al., 1985). They view learning as a qualitative change in a person's conception of a certain phenomenon or a certain aspect of reality, which is a distinct change in how that phenomenon is perceived, how it is understood and what meaning it carries for the learner (Johansson, et al., 1985). This approach depicts *conceptions* as being characterisations of categories of description reflecting person-world relationships. A conception is not visible but remains tacit , implicit, or assumed, unless it is thematised by reflection. In this sense, conceptions are simply categories of interpretation in terms of which we understand the world around us (ibid.). Marton (1981a; 1986; 1990) argues that whatever phenomenon people are confronted with, there seems to be a finite set of qualitatively different ways in which the phenomenon is experienced, conceptualised apprehended, understood or seen. Hence, *phenomenography* is exactly the study of the qualitatively different conceptions (experiences, understandings) of various phenomena. It provides descriptions that are relational, experiential, content-oriented and qualitative (Marton, 1986).

Johansson, et al. (1985) appear to be suggesting that thinking should be described in terms of its *content*, which refers to the thinker's understanding of what is thought about. This idea was explicit in the concept of *intentionality* introduced by the German philosopher Franz Brentano (1973), which was subsequently laid as a groundwork for the phenomenological movement by its founding father Edmund Husserl. According to Brentano all that is psychological includes consciousness, but refers to something beyond consciousness itself. For example, we do not merely love, we love *someone*, we do not merely learn, we learn *something*; we do not merely conceptualise, we conceptualise *something* (Marton, 1986). This is a *relational* point of view in the phenomenographic research approach which presumes conceptual variety. Thus, if a limited number of qualitatively different conceptions of a certain phenomenon can be identified, it seems reasonable to expect that those conceptions can be ordered from less to more advanced conceptions (in relation to some stated criterion). Then *learning* can be considered as an individual's transition from a less advanced to a more advanced conception of a certain phenomenon. Thus, the *phenomenography of learning* is the study of learning as a *change* between qualitatively different conceptions of one and the same phenomenon. Or, in other words, *"a change between two qualitatively different conceptions could be understood in relation to the background of alternative possible changes represented by a structured set of categories of description"* (Johanson, et al., 1985, pp. 255-256). However, an understanding can only be changed if it can be identified. Marton (1990) points out that *"by gaining some insight into how a person understands a particular phenomenon, a contribution can be made to developing another hopefully qualitatively better understanding of the same phenomenon, thereby bringing about* *subsequent development in reasoning and action"* (pp. 604-605). In this sense, the role of pedagogy is to ensure that the transition to a more advanced or "better" understanding of a certain phenomenon (from the limited set of qualitatively different ways of its understanding) is achieved. One requirement for doing this is that the different ways of understanding the phenomenon in question are known.

On the whole, phenomenographers appear to be considering conceptual change as a change in one's relationship with a context. Being able to perceive contexts differently means that one is able to differentiate between them. Changing one's relationship with a specific context means that one has changed as a person (Johansson et al., 1985).

Joan Solomon's work (1983; 1987; 1992) is an excellent example of a more "ecological approach" (cf. Strike & Posner's (1992) revised view on conceptual ecology) to children's conceptual research. Solomon borrowing ideas from social philosophers such as Schutz and Luckmann (1973), or Berger and Luckmann (1967), has proposed that people, out of socialisation necessity, construct two different domains (Solomon, 1983) or worlds (Solomon, 1993b) of knowledge. These are, the domain of general knowledge (life-world knowledge), and the domain (or world) of scientific knowledge, which appear to have different structures. It is argued that people are continually being socialised into a whole social repertoire of knowledge and that such *"socialised knowledge cannot ever, by its very nature, be extinguished"* (Solomon, 1983, p. 50). In this sense, children's ideas about science are seen as *"reflections of the social influences and informal instruction which are at large within the community"* (Solomon, 1993a, p. 8). Moreover, Solomon (1987) argued that children's ideas about nature stem *"not from the logical processes of which science boasts but from the 'common sense' attitude that relies on being able to interchange perspectives and meanings with others"* (p. 66). The notion of *interchange* introduces a *social* element. Hence, Solomon made social interactions in the science classrooms the focus of her research and claimed that learners develop ideas through interactions with the teacher and with one another, which create *"a universe of discourse, a common frame of reference in which communication can take place"* (p. 68). She claims that learning takes place within a *context* and she appears to be interested in the context of social interaction in the classroom.

Solomon (1992) strongly doubts the notion of "conceptual change" and considers it a "problematic title", since it frequently fails to construct a viable explanation about the frequent failure of children to modify their beliefs. She contends that linguistic effects continually reinforce life-world meanings, as it happens in the case of the concept of *energy* that she has broadly investigated. Hence, old ideas *"simply cannot die out and be replaced if they are perpetuated through daily talk"* (Solomon, 1992, p. 108). Moreover, if learners are to continue talking sensibly with friends and family, about concepts like energy, they will have to live with the two quite different sets of ideas *"co-existing in their minds"* (ibid.). It seems that, for Solomon, learning science does not involve conceptual change, as it has previously been described, but learning to distinguish the everyday from the scientific context.

1.2.2. An overview and some working definitions

Conceptual change as a term appears to have links both with the words *concept* and *conception*. It is often the meaning that is attributed to these words in the various studies which determines the nature of conceptual change they envisage.

Hence, the term *concept* appears to be used in the literature in two ways. One concerns classification. This means that having the concept of an animal, a learner should be able to classify accurately any object as an animal or not an animal (see for example Bell, 1981). This meaning of concept has been used by Bruner et al. (1956) and Gagné (1965). Each object compared with a concept is considered to be an instance or a non instance of the concept. When learners appear to be placing instances in sets, or concepts, different from those determined by the community of scientists they are considered to have *alternative conceptions* or *misconceptions*. In this sense, *conceptual change* means learning to classify objects in accord with authority (cf. Chi et al., 1994).

It could be argued though that, this notion of classification, or an ontologically-based taxonomy (Chi et al., 1994) can be a problematic one in two respects. First because the boundaries of concepts are often fuzzy. This means that we might think that we share the same meaning of the concept of animal and in most cases we would agree, but for others there could be a debate (e.g. is a star fish an animal?). Second because objects can be classified on more than one basis and quite often their grouping depends on the context and particularly the purpose in mind. Hence the term animal may include or sometimes exclude humans (e.g. No animals allowed in this building!). There is an attempt by scientists to be precise in the way they use certain terms, but when they apply common words, like force or pressure, in a specialised sense, the words appear to bring with them alternative meanings from other contexts. On the other hand, scientists may try to avoid this problem by using some unique words, but they may in time pass to everyday language, as energy, acceleration, momentum or friction have, gaining other associations which often distort their meaning. In this sense, *conceptual change* can be seen as the adding of contexts and understanding the bases of new contexts. This appears to be a rather difficult kind of conceptual change for young children, as Inhelder and Piaget (1964) showed that it takes some time and maturity to develop the ability to classify objects in more than one alternative ways.

The second meaning of *concept* refers to all the knowledge that a learner has or can associate with the name of the concept. Thus, for example, a learner knows certain propositions about whales (they are large sea animals, they are mammals, they bear baby-whales, etc.); has images of them, that is mental pictures of how they look like, how the move in the open sea; or perhaps the learner may recall an episode of people trying to study or protect them from a recent documentary she has seen. All this knowledge constitutes the learner's concept of whale. In this sense, *conceptual change* occurs whenever the learner learns something new about whales (e.g. grey whales are under extinction). Such additions appear to be easy to teach and learn, or perhaps they look a bit trivial in that they rarely involve reconstruction of the learner's knowledge of the certain concept or other relevant concepts. This minor type of conceptual change is what Vosniadou (1994) refers to as *enrichment* or *accretion*.

Nevertheless, new knowledge may have a far reaching effect on the meaning that a learner places on a term. For instance learning that friction can be the result of rubbing surfaces due to their roughness, or the result of deformation mechanisms that occur on the contact regions of two surfaces, or even the result of an electromagnetic force acting between the surface atoms of two bodies in contact, will change a learner's way of seeing and interpreting various frictional phenomena (cf. Chapter 2). Hence, a learner may be able to understand friction as a sort of holding force which slows down the motion of objects, but may also exist between surfaces that are not in relevant motion with each other. Moreover, that friction may produce heat, or in a more advanced approximation, a learner may understand how triboelectrification produces electricity. In this respect, learners construct *conceptions*, which appear to be idiosyncratic explanatory statements or propositions which often constitute whole systems of explanation about certain phenomena (cf. § 3.8). Conceptions appear to be more complex and difficult to define than either of the above described meanings for concept (cf. Nussbaum, 1989). In this sense, conceptions tend to be personalised ways of understanding phenomena, or ways of "seeing things as" they appear to people (cf. Hanson, 1958). On the other hand, a concept seems to be an intersubjectively construed set of well tested and standardised pieces of information and ideas, which seems to obtain its authority through general acceptability and/or persuasiveness.

A notion of *conceptual change* that aims to change conceptions is often related to restructuring, revision, or accommodation of new conceptions to the learner's existing system of beliefs or knowledge. This kind of change may not always be a radical, revolutionary shift in a learner's conceptions of a phenomenon. It can also be a gradual, evolutionary change in the way that a learner reconstructs her conceptions in an attempt to interpret the world in better or more advanced ways. In most everyday classroom situations, and for most concepts in physics, small gradual steps of change are more likely to happen in such a mode (Millar 1989). In this sense, learning as conceptual change is conceived as "a change in the way of seeing something" (Marton, 1990), within an interactive, non-threatening teaching and learning environment (Bentley & Watts, 1992). Special teaching strategies, assessment techniques, as well as the aid of metaphors, analogies and models often need to be constructed in order to promote the necessary conditions for conceptual change to emerge (cf. § 1.3). This kind of change is considered to be related to prior knowledge and experience, which may help or hinder the restructuring of new conceptions. Children do not seem to abandon old conceptions, but somehow they find ways to reconcile them with the new ones by using their conceptions differently in different contexts. In this way, they develop "conceptual ecologies", where conceptions appear to exist in complex interrelationships with each other. The most convincing and fruitful conceptions appear to survive over time and for certain contexts. Within the context of this inquiry, this notion of conceptual change, or restructuring of children's ideas, is strongly supported and investigated. Nevertheless, it is not implied that this notion of conceptual change is considered to be a fixed assumption for the development of this inquiry. On the contrary, it constitutes a set of ideas which is part of my conceptions as an educational researcher, but which are also open to criticism and test throughout the course of the study.

Some more of these points, as they emerge from this inquiry are discussed again in the last chapter. Some considerations for teaching and learning strategies and relevant assessment techniques, with a focus on conceptual change, follow in the next section.

1.3.0. A theoretical framework for the teaching interventions

In this section, some teaching models or strategies, which are considered to be 'constructivist' and aim to promote conceptual change, are reviewed and discussed. Within these teaching models or strategies, the role of analogies and metaphors is considered to be important in promoting conceptual change, so this issue is also presented and discussed. The last part of this section refers to the issue of 'on-going assessment', as a crucial part of science teaching and to some assessment techniques for obtaining valuable information about children's ideas and understanding of concepts. A link with the general context of this inquiry is pointed out at the end of each part.

1.3.1. Some considerations of 'constructivist teaching models' or 'strategies'

There has been much debate lately focusing on the extent to which constructivist learning theory has become associated with particular models of teaching (Millar, 1989; Matthews, 1994). Some researchers have proposed sequences of teaching strategies based on constructivist principles. Five of these models or teaching strategies or will be briefly reviewed here. They have been chosen because they have some common characteristics and because they are associated with teaching for conceptual change which is of special interest for the present inquiry. They are the following:

- Nussbaum & Novick (1981, 1982); Nussbaum (1985)
- Erickson (1979)
- Hewson & Hewson (1988)
- Osborne & Freyberg (1985)
- Driver & Oldham (1986); Driver (1988, 1989)

The teaching sequences that Nussbaum & Novick (1981, 1982) and Erickson (1979) propose are three-stage or three-phase teaching sequences or models (see fig. 1.3.1).

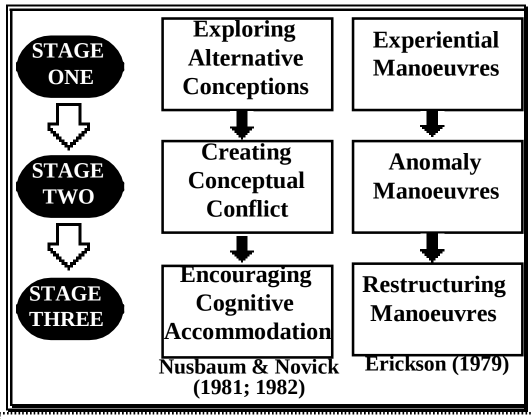

Fig. 1.3.1: The three-stage teaching models proposed by Nussbaum & Novick (1981, 1982) and Erickson (1979) (Osborne & Freyberg, 1985, p. 103)

Nussbaum & Novick (1981, 1982) noted Ausubel's warning that *"preconceptions are amazingly tenacious and resistant to extinction"* (Ausubel, 1968, p. 336) and they accepted that such preconceptions often interfere with the teachers' anticipated learning outcomes. Their main problem was to explain what happens as learners change their conceptions within the context of intended teaching and learning. The content of their teaching was mainly focused on the particulate nature of matter. The 'instructional strategy' they presented, was based on *"the thesis that science concept learning involves cognitive accommodation of an initially held alternative framework"* (Nussbaum & Novick, 1982, p. 183). Put in different words, the task of the teaching process for a certain topic in science is to elicit children's ideas and then modify or change them towards the current or generally accepted scientific view (Osborne & Freyberg, 1985, p. 103).

The 'strategy' they propose is expected to bring about cognitive accommodation. It consists of three stages or 'phases'. The first phase is about *exposing alternative frameworks* and it is attempted to ensure that every learner is aware of her own preconceptions. This may be achieved through an 'exposing event', where the learners are expected to make their existing ideas explicit in order to interpret it. The learners are encouraged to express and describe their views in a verbal, written or pictorial way and the teacher helps them along to state these ideas clearly and explicitly in order to enable them recognise what they cannot explain within the context of their pre-existing ideas. Discussion of all the alternative views presented by the fellow learners is strongly encouraged by the teacher in order to better understand the features of each view. What is expected to come out of such activities is 'dissatisfaction' with the learners' existing ideas and at that point the teacher reinforces that dissatisfaction by providing the learners with a 'discrepant event'. Then *'conceptual conflict'* is likely to result. Nussbaum & Novick (1981, 1982) imply that this conceptual conflict should be sufficient to persuade the learners that their existing views require modification. In the last phase there is an attempt to *encourage cognitive accommodation* by helping learners to search for a solution to their conflicting ideas and thus, develop modified ideas (see fig. 1.3.1). Cognitive accommodation is not easily achieved and as they contend it *"is not a process which one can schedule monitor or guarantee. What one can do is to try to characterise it and to look for instructional strategies that may facilitate its occurrence"* (Nussbaum & Novick, 1982, p. 186).

Erickson (1979) raises a similar set of proposals referring to children's conceptions of heat. In the first stage of his model the learners should be encouraged to become familiar with a wide range of phenomena and in doing so they should develop a set of intuitive ideas and beliefs. As Erickson (1979) suggests:

> Such encounters or *experiential manoeuvres* should be of sufficient depth to allow the students to clarify their ideas and develop the confidence to begin making predictions (p. 228).

The second stage contains *anomaly manoeuvres* which are designed to introduce elements of uncertainty by creating situations that lead to unexpected outcomes. There is an expectation that the uncertainty will eventually be resolved *"with a type of reorganisation or restructuring of the child's intuitions or beliefs"* (ibid.). The third stage is a set of *restructuring manoeuvres* to assist the learners to accommodate the unexpected outcomes. According to Erickson (1979), these restructuring manoeuvres could be accomplished in many different ways such as peer group interactions or more direct interventions by the teacher (see fig. 1.3.1).

Hewson & Hewson (1988) claim that the research in science instruction which is based on conceptual change ideas (they refer to Minstrell (1982) and Hewson (1986)) makes important contributions to an appropriate conception of teaching science. They identify some key points that the teachers should have in mind in order to help learners overcome their naive or intuitive conceptions. These points are the following:

- it is necessary for the teacher to be able to diagnose learners' thoughts on the topic in hand by using a pre-test based on prior research, or by posing questions aiming to elicit their conceptions.

- the learners should be able to clarify their thoughts through individual work or group discussion guided by well-planned questioning. In terms of the 'conceptual change model' (Hewson, 1981; Posner et al., 1982), the learners should be able to understand the basis on which their conceptions are *plausible* and perhaps *fruitful* to them.

- the teacher should ensure that there is a direct contrast between the learners' views and the 'desired scientific view'. This can be achieved by presenting the 'desired view', or somehow by making it emerge from the class. This means that the learners should become *dissatisfied* with their existing conceptions, according to the 'conceptual change model' (op. cit.).

- then the teacher should provide immediate opportunities for the learners to use the desired view in explaining a phenomenon which can be achieved through carefully-planned questioning or with a demonstration of a certain phenomenon. This enables the students to see that the 'desired view' is a *plausible* one.

- after that the students should be encouraged to *apply* their newly acquired understanding and conceptions to different examples closely or more distantly related to the original one. This helps the learners to see the *fruitfulness* of their new conceptions.

Another teaching sequence for changing children's ideas has been proposed by Osborne & Freyberg (1985). They aimed to achieve three specific objectives:

- *clarification* of the learners' existing views
- *modification* of these views towards the current scientific view
- *consolidation* of the scientific view within the background experience and values of the learners (pp. 107-108).

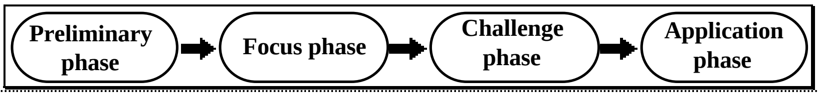

Fig. 1.3.2: The 'generative learning' model of teaching (Osborne & Freyberg, 1985)

The teaching sequence they proposed, which they call 'generative learning' model of teaching, is composed of three distinctive teaching phases, namely *focus, challenge* and *application*, but these are preceded by an explicit teacher preparation phase (see fig. 1.3.2). In that *preliminary phase,* the teacher's preparation should include: ascertaining the 'typical' children's ideas and their prevalence in the class concerned, understanding of scientists' ideas in their attempt to describe and explain certain phenomena and an appreciation by the teacher of her ideas that she intends to use in the description and explanation of the phenomena under consideration. The aim of the *focus phase* is to provide a context for later work. The activities involved could focus attention on particular phenomena or could elicit learners' ideas about their meaning of words or concepts, or even a combination of both. The teacher should create a non-threatening learning environment and should provide motivating experiences and discussion, in an attempt to make explicit to the learners that they should take responsibility of their learning and that they should try to clarify and understand their own views. During the *challenge phase* the learners present their views to a group or the whole class and all the deferring views are sought, commented and discussed. The teacher introduces the scientists' view, where necessary, at an appropriate level of "sophistication and language" for the learners. Some critical tests and/or experiments could be conducted, to check the preferably proposed views of the learners. The teacher has an important role here in order to decide what kind of activities will be planned for groups and for the whole class. If this phase is successful, it shall end with the learners asking questions in their attempt to accommodate new ideas. The *application phase* can be some time spent on problem solving within the context of the 'accepted scientific viewpoint', or further discussion and application of the new ideas in different contexts in order to increase their persuasive status. The teacher should encourage the learners to think about certain phenomena in terms of the new viewpoint and she should also encourage the learners to adopt a reflective thinking approach.

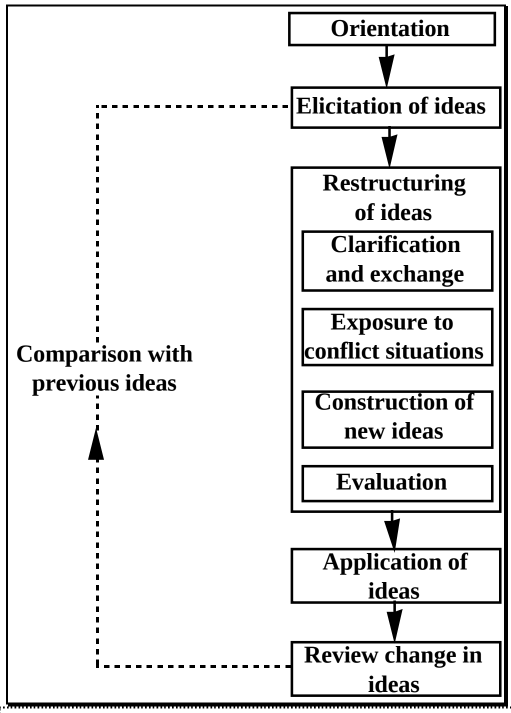

Fig. 1.3.3: A constructivist teaching sequence presented by Driver & Oldham (1986) or Driver (1988, 1989).

The teaching sequence presented by Driver & Oldham (1986) or Driver (1988, 1989) starts with an *orientation* phase, which is a scene-setting activity where the learners' interest and attention about the topic are expected to be aroused through discussion and exchange of ideas and opinions (see fig. 1.3.3). The second phase is called *elicitation* and it is usually conducted in small groups. Each group works on a certain issue and then they are asked to present their work to the rest of the class, usually by preparing a poster and then they pin it on the wall to be used for later reference and further discussion. Not only learners' alternative ideas about the topic are expected to be elicited, but the learners and the teacher are also expected to become aware of them by making them explicit or by clarifying them. The heart of this teaching sequence is the *restructuring* phase. A wide range of activities are involved here like broadening the range of application of a conception or focusing on the differentiation of a conception. There can possibly be an exposure of the learners to conflict situations, which will challenge and modify or change their conceptions. Analogies or models can be introduced and discussed in order to help learners use their prior knowledge to understand the new knowledge. Sometimes the input of scientific view is necessary to help learners construct new ideas and conceptions and evaluate them under the light of new perspectives. Then the phase of *application* provides the learners with opportunities to apply their revised conceptions in a variety of ways like practical construction tasks, imaginative writing tasks or problem solving. At the end of this teaching sequence the learners are given the opportunity to *review* their prior ideas and conceptions and find out about the extent and the ways in which their thinking has changed. The posters they produced earlier may be modified or new ones may be constructed and compared with the earlier ones.

All of these teaching sequences or models have some common characteristics which may include the following:

- provision opportunities for the learners to make their prior conceptions explicit
- encouragement for the restructuring of learners' conceptions through a range or sequence of strategies, such as discussion, exchanging of ideas and opinions or even elements of Socratic dialogue
- emphasis is given in experimental demonstrations and in learning experiences with conflict situations, which are anticipated to promote conceptual change learning
- the learners are finally encouraged to apply their newly acquired conceptions to experience their fruitfulness.

White & Gunstone (1989) emphasised the importance of the role of 'metacognitive strategies' in learning. They refer to the importance of learners being encouraged to reflect on their learning and understandings and generally take responsibility for their own learning. Metalearning strategies help cognitive restructuring to occur, because they strongly support learners to *"learn how to learn"* new concepts (Novak & Gowin, 1984). That is, as they learn material, learners should at the same time be learning something about the process of effective learning. Most of the authors cited above strongly support metalearning processes in science teaching and learning.

Some authors have questioned and criticised the appropriateness of linking any particular teaching approach to constructivist learning theory. Matthews, (1994) poses the question of whether or not the constructivist teaching techniques and understanding of learning are unique to constructivism and he claims that:

> The answer is clearly no. Much of the best constructivist technique-with its emphasis of actively engaging the learners in their own learning and paying attention to the prior beliefs and conceptualisations of students-is at least as old as the Socrates' interrogation of the slave boy in the *Meno* (p. 144).

Matthews (1994) also criticises the extrapolation of constructivist learning theory to curriculum and pedagogical issues. He claims for instance, that the curriculum does not flow from learning theory alone. A learning theory may indicate *how* something should be taught, but *what*, *how much* should be taught and to *whom*, follow different or additional considerations, such as *"judgements of social needs, personal needs, the relevant merits of different domains of knowledge and experience and finally due political decision making"* (Matthews, 1994, p. 145).

Millar (1989) also claims that a constructivist model of learning does not *"logically entail a constructivist model of instruction"* (p. 589). Put in other words *"the constructivist model of learning does not carry any necessary message about models of instruction"* (ibid.). This doesn't mean, of course, that the constructivist research programme has no contribution to make to the improvement of science education. What Millar (1989) suggests is that this contribution should be seen more in terms of improving the sequencing and pacing of science curriculum and less in terms of changing teaching styles and approaches. He believes that constructivism has an important role to play in mapping the general features of pathways individuals follow towards more productive understanding. Thus, he proposes that instead of attempting to identify a constructivist-based model of instruction, it may be more productive to focus on increasing the active involvement of learners, as this is a requirement for reconstruction to take place.

In general, teaching strategies such as those cited above, portray a style of teaching in which both teachers and learners are cognitively active and engaged. Teachers using these strategies encourage learners to express their ideas and interpretations in their attempt to explain and understand the world. Learners' verbal and written statements are used to monitor their understanding and their progress through the process of conceptual change. Learners are constantly encouraged to think more rigorously about familiar phenomena, to modify their explanations in the light of new information, and to develop explanatory and problem-solving skills. These teaching strategies are designed both to engage learners in activities like those of the scientifically literate adults and to provide them with the support and practice they need to master these activities. Thus, in doing so, conceptual change teaching models or strategies should not only promote the mastery of scientific conceptions, but they should also promote a general understanding of the nature of science.

In the present inquiry, all of these ideas and principles are considered carefully and there is an attempt to relate them to practice, through the two teaching interventions on the concept of "friction", in England and in Greece. These teaching interventions aim to:

- make learners aware of their conceptions throughout the whole process of teaching and learning about friction and frictional phenomena
- organise classroom activities and experimental arrangements so that the learners can test the fruitfulness of their conceptions and then discuss their ideas in groups or with the whole class
- present an analogy (with two pieces of a jigsaw puzzle) in order visualise and explain the interlocking of the roughness of surfaces and the creation of friction
- put newly acquired conceptions into practice by discussing and explaining some everyday frictional phenomena and identify some aspects of learners' conceptual change
- assess the outcomes of the teaching interventions and learners' conceptions by using techniques for exploring and representing conceptions, such as concept maps and children's writing and drawings, within a framework of on-going assessment (cf. § 1.3.3)

The ways that these aims were put into practice are described in the following chapters (cf. § 4.2 and § 5.2), whereas anticipated and/or unexpected learning outcomes are discussed in the last chapter.

1.3.2. On the role of analogy and metaphor in the science teaching and learning process, with an emphasis on conceptual change

It has been argued that analogies may be valuable tools in the teaching and learning of difficult concepts in science (Webb, 1985; Brown, 1994; Dagher, 1994). There are also sceptics who claim that analogies may be "double-edged swords" (Glynn et al. 1989, p. 387) or that analogies "may give birth to as many monsters as healthy babies" (Duit, 1991, p. 649). Analogies are often used by scientists in order to represent, analyse or communicate their ideas or findings. As Nersessian (1992) contends:

> ... 'abstraction techniques' such as analogy, imagery, thought experiment and limiting case analysis, [has] played a central role in both the construction of new scientific representations and the communication of [them] to others in the scientific community (p. 49)

If this is the case in the scientific community, it could be argued that analogies may have some similar effects for the pupils' community, bearing in mind though, all the significant differences in the structure, function and commitment of two such communities (Nussbaum & Novick, 1982, p. 187; Nussbaum, 1989).

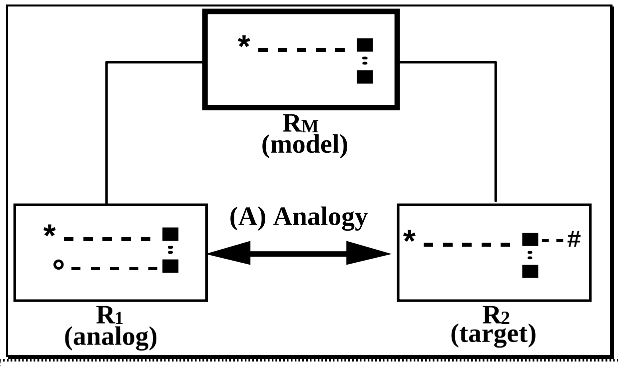

Fig. 1.3.4: On the meaning of analogy (Duit, 1991, p. 650)

In this inquiry the meaning of the term analogy[1] is adopted from Duit (1991) who sees analogy in reference to comparisons of structures between two domains. His view is illustrated in fig. 1.3.4, where all of boxes stand for 'representations' (**R**). As it is portrayed, in a pictorial way, there may be identical features in parts of the structures of $\mathbf{R_1}$ and $\mathbf{R_2}$. The box with $\mathbf{R_M}$, represents this structural identity, thus $\mathbf{R_M}$, is called a model (Duit, 1991, p. 649). The

[1] The word **analogy** comes from the Greek word 'αναλογία' [analogia] which means a harmonic relation towards something, a similarity, a parallelism, a symmetry, characteristics which can be identified within the context of analogical relations.

analogical relation that exists between $\mathbf{R_1}$ and $\mathbf{R_2}$ is in reference to the structure presented in $\mathbf{R_M}$ (see fig. 1.3.4). Analogical relations may exist at different levels. Duit (1991) takes for example 'water and electric current' as two representations ($\mathbf{R_1}$ and $\mathbf{R_2}$) of two domains of reality. This 'water-flow analogy' for electricity is discussed thoroughly in Gentner & Gentner (1983, p. 108). Such an analogical relation as portrayed in fig. 1.3.4, may be called an analogy of the first level, although analogical relations may also be developed between two models.

Models like analogies deal with the mapping of the structure of different domains. Usually, they represent parts of structures of target domains. In this sense, models may provide analogies and this is actually part of their identity and existence.

Duit (1991) uses the term ***analog*** (also used in Glynn, 1991) to refer to the domain that functions as a "base" (Gentner & Gentner, 1983) or "source" (Rumelhart & Norman, 1981) in the purposes of learning and teaching. He uses the term ***target*** (also used in Gentner & Gentner, 1983; Glynn et al., 1989) to refer to the domain that is *"explained or learned by harnessing the analogy"* (Duit, 1991, p. 650). An analogical relation is symmetrical because it is based on identities of parts of structures. It is not implied, therefore, any kind of hierarchy between the *analog* and the *target*, since they both indicate the purpose of the analogy use, or of the analogical reasoning. On the nature of analogical reasoning Vosniadou & Ortony (1989) summarise the following:

> There is general agreement that analogical reasoning involves the transfer of relational information from a domain that already exists in memory (usually referred to as *source* or *base* domain) to the domain to be explained (referred to as *target* domain). Similarity is implicated in this process because a successful, useful analogy depends upon there being some sort of similarity between the source domain and the target domain and because the perception of similarity is likely to play a major role in some of the key processes associated with analogical reasoning (pp. 6-7).

Thus, an analogy may explicitly compare the structures of two domains and it indicates similarities or identities of parts of structures. Another important aspect is that analogies may make new information more concrete and easier to imagine and therefore they may be useful means in the active process of linking what is already familiar, in an attempt to understand the unfamiliar, constructing, in a way, similarities between the new and the already known. This emphasises the significance of analogies within a constructivist learning approach (Duit, 1991).

Employing an analogy does not solely develop learning within a new target domain. It also opens up a perspective of reorganising or restructuring the analog and hence develop both the analog and the target. Thus, an analogy may be a 'two way' process, if the roles of the analog and the target are viewed interchangeably to each other. For example, the analogy "the hydrogen atom is like the solar system" (Gentner & Gentner, 1983, p. 101) may be viewed interchangeably from the point of view of the analog (the hydrogen atom) or the point of view of the target (the solar system), or the other way round. This may develop analogical relations and restructure both domains.

A metaphor[2] compares two domains implicitly by highlighting features or relational qualities that do not coincide in these two domains. The grounds of such a comparison are often hidden and they have to be revealed or even created by the addressee of the metaphor. Within the framework of fig. 1.3.4, it could be argued that a metaphor points out major dissimilarities in order to create springboards for the mind, to search for similarities. As Duit (1991) puts it:

> Analogies and metaphors may be viewed as polarities, which in principle may be transformed into one another; that is analogies may be seen as metaphors, metaphors as analogies (p. 651).

A "surprise" or an "anomaly" is often created by a metaphor and that's what makes it important for the learning process. For example the metaphor "photosynthesis is the mother nature's way of baking a cake", may provoke learners' thought because of the paradoxical and strange meaning that it conveys, but it might, as well, be valuable and fruitful for the learners to find out how it could possibly make sense (Duit, 1991, p. 667). Gowin (1983) observes that:

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[2] The word **metaphor** comes from the Greek word 'μεταφορά' [metafora] deriving from the active infinitive 'μεταφέρειν' [metaferein] which means carrying over, transfer or even take something further.

> Something seems to happen to us when we first read a fresh metaphor. We are reorganising our patterns of previously organised meaning. In that sense disciplined exploitation of metaphor is a form of conceptual grasped meaning. Put differently, if we want to grasp the meaning of new concepts, we should ask the teachers to compose them to metaphors for us. (p. 57)

Metaphors may help us to see even the familiar in totally different ways and provoke unique connections with the unfamiliar, by opening new perspectives to us which never existed before.[3] This is the "generative power" (Gowin, 1983) of metaphors that makes them valuable tools in conceptual change learning, because they manage to create surprises, discrepancies or even cognitive conflicts.

Consequently, it may be argued that analogies differ from metaphors but only to a slight degree (Duit, 1991, p. 653). Every good analogy should contain some aspects of surprise or anomaly or there should be a potential for the analogies to be used in such a way. In this sense it is the 'metaphorical aspects' of good analogies that make them valuable tools for conceptual change learning (ibid.).

The great challenge for teachers is to make analogies work through careful considerations and planning. Clement (1987) reported that although it was attempted to use analogies in learning situations, it didn't bring the expected results as learners failed or were not able to 'see' the analogy. Hence, analogical reasoning did not happen and the analogies failed to play their intervening role. There could be several alternative interpretations to this, like the difference between the rationality of the teachers and the rationality of the learners, in the notion that things which are obvious or apparent for one side may not be equally obvious or apparent for the other side. Another reason could be that the learners are not familiar with the analog domain

[3] Gowin (1983, pp. 58-59) discusses a story of a group of product development researchers who were considering how to improve the performance of a new paint brush with synthetic bristles. No matter what they tried in the beginning they had moderate success. Then, one of them had a feeling that "a paint brush is a kind of pump". This may sound a strange statement, but it manages to provoke thought to invent analogical relations between 'the paintbrush' and 'the pump'. In a verbal description a pump is *"an instrument that moves liquid from one place to the other by pushing or sucking it through a channel"* (ibid.). As for the paint brush, the researcher pointed out that when it is pressed against the surface, the paint is forced through the spaces between the bristles onto the surface. Thus, the paint flows through the channels formed by the bristles as they are deformed by the bending of the brush. Sometimes the painters vibrate the brush when applying it to a surface so as to facilitate the flow of the paint, so the arm pumps the brush to get the paint out. Hence, by getting involved with this metaphor, the researchers noticed new features of the paintbrush and the painting process.

(Gabel & Sherwood, 1980) or they may not be familiar with a significant part of it and as a result misconceptions could be transferred from the analog domain to the target domain or vice versa (Duit, 1991, p. 657). Thus, it is essential to make sure that there is adequate prior knowledge of the analog domain, which will prepare the ground for fruitful analogical relations with the target domain.

Clement and a group of researchers at the University of Massachusetts have developed an approach for "remedying" learners' misconceptions via what they call "bridging analogies" (Clement, 1987; Brown & Clement, 1989; Brown, 1993; Brown, 1994). They also noticed that analogies are often unsuccessful because learners do not understand the analog or they fail to draw the analogies intended. They carefully tried to search for analog situations that trigger a correct intuition which may lead to understanding of the target situation. They call these analogs "anchors" or "anchoring examples". It is often the case that the "jump" between the analog and the target is too big, even if the anchor is familiar to the students. Thus, the distance to be covered has to be split into smaller steps or jumps, which are called "bridges" or "bridging analogies". For example the instance of a book lying on a table, is one of those that arouses difficulties in the conception of the Normal force (N) from the table towards the book. Learners have difficulties in comprehending that the table "pushes up" the book via a force. Instead, learners have alternative conceptions for the book laying on the table, such as the following:

- because of gravity there is no upward force
- the table has no agency for exerting a force
- the table is not pushing or pulling
- the table is just in the way
- the book would move up if the table exerted a force (Brown, 1994, pp. 205-206).

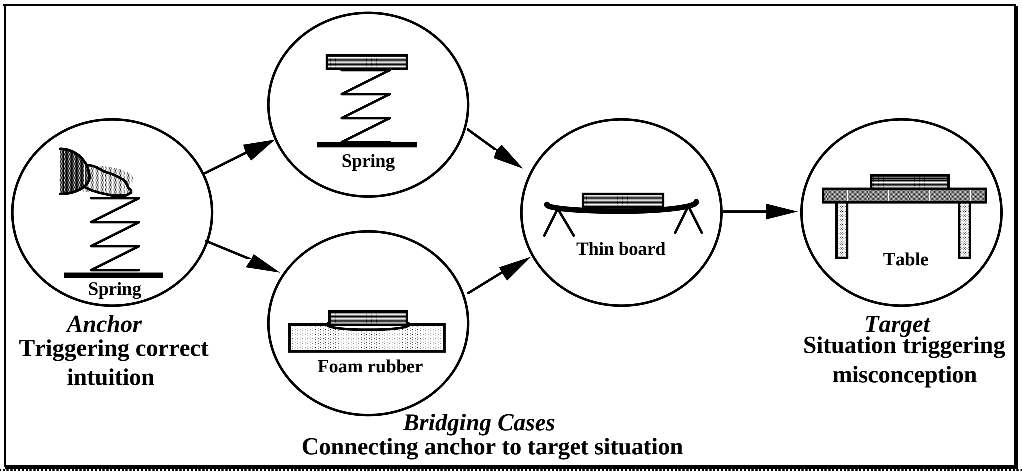

Fig. 1.3.5: This a pictorial representation of the *anchor, the bridging cases* and *the target* within the "bridging analogies approach" (Clement, 1987; Brown & Clement, 1989; Brown, 1994).

To guide the learners to understand the target situation, namely, that there is an upward force acting on the book due to the action of the table a sequence of analogies is introduced and discussed (Clement, 1987; Brown, 1994). The *anchor* is a spring compressed by a finger where a force acting back from the spring can be felt and conceived, therefore this situation triggers correct intuition. From this anchoring situation Clement (1987) proceeds toward the target situation via two intervening bridging situations (see fig. 1.3.5). They are the book lying on the foam rubber and the book laying on a thin board. Brown (1994) has also introduced and/or used alternatively the bridging analogies of the book laying on a spring or a learner holding a heavy dictionary in her hand in an attempt to provide more "steps" towards the target situation.

Another case of particular interest for this inquiry is described in Brown & Clement (1989) who investigated the role of an analogy in the process of changing a conception of a target situation which referred to the mechanism of sliding friction. The target situation was a shuffleboard puck sliding on the floor, where the floor exerts a frictional force in a direction opposite to the motion of the puck which slows it down. In the initial phases of the "tutoring interviews" that they conducted, learners were questioned about the existence of a force exerted from the floor on the sliding puck. They replied that the floor did not exert such a force. Then, two slightly intermeshed hairbrushes, one clamped to the table and the other drawn horizontally across it to the right, were used as an anchor situation (see fig. 1.3.6).

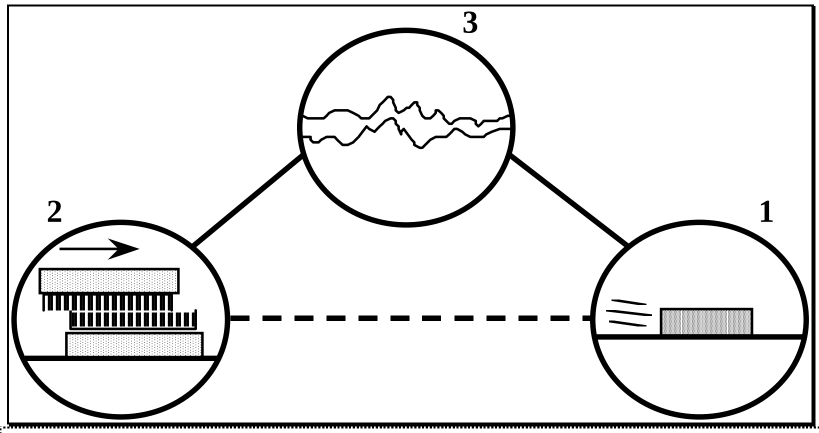

Fig. 1.3.6: An analogy diagram, where the *target situation* is a sliding shuffleboard puck **(1)**, the *anchor* is that of two slightly intermeshed hairbrushes **(2)** and the '*microscopic model rather than the analogy'* is a magnified view of the puck and the floor **(3)** (Brown & Clement, 1989, pp. 245-247).

Although a learner believed that the lower brush would exert a force to the left on the top brush, he did not see this as analogous to the sliding puck. As a result, the interviewer asked the learner to consider an intermediate situation of a magnified view of the floor and the puck. This could be more accurately called "a microscopic model rather than an analogy" (Brown & Clement, 1989, p. 246). After the learner had considered this intermediate situation, he mentioned that both the floor and the puck would appear "hilly and rough" and he indicated that the interface of the bumpy surfaces was "the same thing" as the hairbrushes (ibid.). Thus, although the learner initially believed that there was no force exerted on the puck affecting its motion, by the end of the interview, a successful attempt to promote conceptual change was achieved, since it made good sense to him that the floor would exert a force in a direction opposite to the motion of the puck. The learner seemed to have created an explanatory model through which he viewed the puck and the floor as '*bumpy'* or *'bristly'*, which is different from a simple analogical projection of the puck and the floor *'as like'* hairbrush bristles. This generally applicable explanatory model promoted conceptual change with the enrichment of the target situation, which was achieved through the consideration of the magnified interface of the floor and the puck (ibid.).

The approach described in the previous two cases is based on a constructivist framework of teaching and learning, since it is child-centred, it involves negotiation of views and ideas and it even employs aspects of Socratic dialogue. On the other hand, some points of critique would be that it is difficult to find good anchoring situations or bridging analogies, or that learners might need some further discussion and clarification on the analog (anchor) situation, since they could have some difficulties in conceiving certain aspects of it (in the first case, for example, the finger could be seen as the active agent, not the spring, even if they feel some kind of reaction) (Duit, 1991, p. 665).

In the present inquiry, the analogy of the "impressed hairbrushes" was not used to represent the interlocking of surfaces (e.g. a block of wood on a tabletop). It was considered to be rather out of hand or a bit abstract for young children mainly in terms of the complexity of perception when it comes to what actually happens in the interface of the two impressed hairbrushes. The metaphorical effect of friction is not clearly seen through this analogy, although it could be claimed that it is more easily sensed. Nevertheless, an analogy with two interlocking fragments of a jigsaw puzzle was preferred and used for the same purpose (cf. § 4.2.5 and § 5.2.3). It is considered to be more illustrative and more adequate for young children. A presentation of how this analogy was put into practice can be found in the teaching interventions of the two studies (England & Greece) in the following chapters.

1.3.3. On-going assessment and some techniques used for gathering information for assessment in the context of this inquiry.

Assessment is considered to be an essential part of a teaching intervention. It is claimed that some types of 'on-going assessment', which are used in this inquiry, have helped to reveal information about children's conceptions, understandings and representations of the phenomena under study (cf. § 4.2.6., § 4.3, § 5.2.4, § 5.3).

The term "assessment" is used here with a broad meaning. As Harlen (1992) contends:

> It is generally agreed that assessment in the context of children's achievements in school is a process of making judgements about the extent of these achievements. The judgements are reached on the basis of information which has been gathered about performance and which is compared with some kind of expectation. (p. 158)

There are various ways in which information for assessment can be collected and similarly there are various bases for judging it. This way, a variety of different kinds of assessment is created. It is important to make clear that it is not assumed that assessing is the same as testing. Assessing is one of the possible ways of gathering information about children, while testing is one of the possible ways of assessing. Assessment involves a description of what children have done rather than a collection of the evidence itself. In Harlen's (1993) words:

> It replaces the real thing by a summary of it: a comment, a mark, a spoken word; even a smile or a frown or other gesture can be a result of assessment (p. 137).

One of the types of assessment is "on-going assessment" which is also described as 'formative' or 'diagnostic'. It involves the assessment of information which is gathered almost imperceptibly during normal, daily interchange between teacher and learners and it mainly has an idiosyncratic orientation. Its main purpose is to help teachers in making decisions which refer to the learning of individual pupils and/or groups of pupils and it is part of the regular day-to-day planning and teaching. This is different to 'formal' or 'summative' assessment which involves the gathering of information through carefully devised standardised tests, usually under controlled conditions. The information gathered from on-going assessment involves an identification of "where children are" in their learning, in order to create feedback for the teaching and learning process for further action. Valuable information of "what has or has not been achieved", may also be provided. Ideas, skills and attitudes as well as other aspects of personal development may be assessed by using various techniques for on-going assessment (Harlen, 1993, p. 138).

In this context, certain assessment techniques were used after the teaching interventions, in the present inquiry. They were mainly the following:

(a) children's drawings and comments on drawings,
(b) children's writing on a specific task, and
(c) concept maps (only for the study in England).

1.3.3.a. Children's drawings

Children's drawings may reveal a lot of information about their understanding of a concept or about alternative ideas they have developed. As Harlen (1993) puts it:

> Children's drawing, which may not at first seem to give particularly rich information about their ideas, can be made to do so if they are asked to draw not just what they see, but what they think is happening or what makes something work (p. 151).

At the end of teaching interventions, in both studies, the children were given an assessment leaflet and they were asked to draw a magnified section of the touching surfaces of a block of wood sliding on a tabletop (see Appendices VII & VIII). This was expected to reveal ideas about the nature of the surfaces in contact and the interlocking of surfaces as a main element for the creation of friction (cf. § 4.2.6 and § 5.2.4). Additionally, in Greece children were given a second assessment leaflet a week after the teaching intervention. They had to represent with an arrow the force of friction wherever they thought it existed in the six depicted instances of the leaflet (see Appendix VIII). This was expected to reveal information about their understanding of the concept of friction which was present in all of the depicted instances (cf. § 5.3).

1.3.3.b. Children's writing

Children's writing may be more productive in revealing their ideas about a certain concept, especially if they have to express their ideas in specific written task (Halren, 1993). Not all of the children can fully express their ideas in a written form or at least they may have difficulties in written tasks. Thus, their writing needs to be treated carefully and help should be provided when needed.

In this inquiry children were asked to write down their opinion on how the "interlocking of surfaces" effects friction (see Appendices VII & VIII). This question was strongly linked with their investigations with blocks of wood which were slid on various surfaces and this was expected to reveal insights concerning their conceptions on how surface friction is created (cf. § 4.2.6 & § 5.2.4).

1.3.3.c. Concept maps

As Novak (1995) claims "concept maps are tools for organising and representing knowledge". Concept maps include concepts which are usually enclosed in circles or boxes and relationships between concepts and propositions which are indicated by connecting lines between concepts or by words which specify a propositional relationship between two concepts. He defines *concept* as "a perceived regularity in events or objects, or records of events or object, designated by a label" (ibid.). *Propositions* contain two or more concepts connected with other words in order to form a meaningful statement which is often called a *semantic unit.* One of the characteristics of concept maps is that concepts are represented in a hierarchical way, from the more general and inclusive to the less general and more specific and of course this is context dependent. Another important characteristic is *cross-links* which are mainly propositional connections between concepts in different domains of a concept map which reveal their relationships. Finally, specific *examples* of events or objects may be added in certain parts of a concept map which help to clarify the meaning of a given concept.

Concept maps may be used as powerful learning tools but also as assessment tools, encouraging students to use meaningful learning patterns (Novak & Gowin, 1984; Novak, 1990; Mason, 1992). One of the extensions that concept maps can have as assessment tools is to explore understanding of a limited aspect of a topic or of a specific concept (White & Gunstone, 1992). They have been used even with young children providing "an indication of whether or not a child's conceptions have been altered or whether in fact anything has been learned or understood" (Kilshaw, 1990, p. 36). Learners may also be given a list of terms to draw a concept map and identify relationships among them, without placing a lot of emphasis on hierarchies among concepts (Harlen, 1992, p. 179). This is mainly the context in which concept maps were used in this inquiry, without underestimating, of course, the learning value of the construction and use of concept maps (cf. Appendix VIa & VIb and § 4.3.).

1.3.4. A concluding remark

Several elements from most of the theoretical approaches on teaching and learning science as a process of conceptual change have been considered and used throughout the course of this inquiry (cf. all three sections of Chapter 1). It has been a very difficult task to create a synthesis of different, and often opposing points of view, and then try to pin them down into classroom practice, within the thematic context of this inquiry (cf. Chapter 2). As Solomon (1992) contends, research students "have found it hard to put into action in the classroom" the theoretical approaches of teaching and learning for conceptual change (p. 30). Nevertheless, an attempt has been made and it is presented in the chapters that follow (mostly Chapters 4 & 5).