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ASPECTS OF CONCEPTUAL CHANGE OF 10-11 YEAR-OLD CHILDREN IN ENGLAND AND IN GREECE: THE CONCEPT OF FRICTIONAL FORCE

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A thesis submitted in partial fulfilment of the requirements of The Nottingham Trent University for the degree of Master of Philosophy

July 1997

Acknowledgements

I am deeply grateful to a number of people for their assistance and support for the fulfilment of this thesis.

First of all I am extremely grateful to *Professor Gordon Bell* who offered me an opportunity to study at The Nottingham Trent University (Nottingham Polytechnic, at that time) by providing me with a scholarship and a hospitable working environment. It has always been a pleasure to discuss with him several academic issues. His advice helped me a lot in grasping some philosophical ideas in the beginning of this inquiry.

I am grateful to The Nottingham Trent University for their financial assistance.

I would like to thank *Mr. Dennis Fox*, my supervisor, for all the helpful discussions and his advice, especially in the first stages of this research project. He has pointed out several issues that influenced the development of this inquiry.

I am also grateful to *Dr. Peter Ovens*, my supervisor, for his helpful interventions throughout this long-standing commitment. He has always been there for me, to help with all the difficulties that arose. I am most grateful for his comments and suggestions during the phase of the development and the writing of this thesis.

I would like to thank *Professor Michael Bassey* for his helpful contributions and discussion on research methodology, in a series of the post-graduate seminars. He has been very inspiring and influential. I would also like to thank *Mary Hayse* and *Jane Jonston* for their help in various issues.

I am grateful to a number of members of staff at the Nottingham Trent University, like the people at Primary Base, *Clark and Imogen*, *Carren Robbers*, responsible for the interlibrary loans and *John*, the librarian, who often helped to find my way out, in a search for books and articles.

I would like to thank *Anna Traianou* for sharing with me several learning experiences and common anxieties in the space-time continuum of life, for the last ten years or so. Quite often we managed to share common headaches for various issues. I have always enjoyed the conversations on Greek history and politics in the early morning hours.

Since part of this research project was carried out in Greece, I am grateful to a number of people at The University of Crete for their advice and support.

I am deeply grateful to *Prof. Dr. Demetris Ploumbides* for clarifying and highlighting concepts of physics, especially on friction and frictional phenomena, as part of this research project. He has always been very inspiring and he knows that his words always meant a lot to me. He has supported me in difficult moments, in his own thoughtful and influential way.

I am grateful to *Prof. Dr. George Flouris*, for his support and for helping me to arrange the educational setting for the study in Greece. I would like to thank *Prof. Dr. Yiannis Pyrgiotakis*, currently vice-rector of The University of Crete, for his assistance in the beginning this inquiry. I would also like to thank *Dr. Pella Kalogiannakis, Dr. Vasilios Makrakis and Dr. Petros Anastasiades*, for their help and their suggestions.

I am grateful to *Dr. George Rousopoulos* and *Meni Tsigra* for their moral support and their helpful discussions, which I have missed lately.

A "thank you" doesn't seem to be enough for my friends in Greece who have supported me, in their unique personal ways, along the extended route of this research endeavour. Thus, I am grateful and deeply appreciative to the following friends:

Mr. Takis Trouposkiadis, a good family friend, who has helped me in difficult moments. His contribution has been crucial in the completion of this thesis.

George Passias for helping me in various ways and for sharing with me his thoughts and plans for the future, which often kept me going.

Nikos Petropoulos, Christos Mellas and Panos Metaxakis, good friends who have helped me in various moments of my life and unfortunately I have lost contact with them, in the last three years or so, with a promise that I'll get back to them as soon as I am through with my military service.

George Malandrakis, Elias Karasavvides, Yannis Goumenakis, Andreas Kollias, Vasilis Dafermos, Maria Papamattheou, Marios Hatzopoulos, Elli Korrou, Theodore Stamatakis, Michael Melachrinoudis, friends with who I have shared experience in academic and other contexts, for several years.

I am indebted to my parents *Lambros and Maria*, and my sister *Sylvia*, for their love, constant support and patience for all these years. I dedicate this thesis to them as a small symbol of my gratitude.

Last but not least, I am deeply grateful to *Maria* for her love, moral support, encouragement and patience for the last two years or so.

Dedicated with gratitude to

My parents,

Maria and Lambros

Abstract

This is an inquiry carried out in two educational settings, one in England and one in Greece, with 10-11 year-old children and it is guided by a constructivist view of teaching and learning. In both studies, children's conceptions on frictional phenomena and frictional force have been elicited before and after a teaching intervention and they have been compared in order to highlight some aspects of conceptual change. During the teaching interventions the children investigated friction with blocks of wood which were slid on various surfaces of tabletops (sandpaper or plastic laminate) and they discussed their conceptions of friction in everyday life situations with their classmates and the teacher.

A modification of the Interview-About-Instances technique has been used to elicit children's conceptions before and after the teaching interventions in both studies. Some additional assessment techniques, like concept maps and children's drawings and writing, have also been used after the teaching interventions in order to obtain information on children's conceptions. This was done to cross-examine inferences drawn from the analyses of the interview data.

The Pre-Intervention interview analysis focused on the elicitation of groupings of conceptions and alternative conceptions about frictional phenomena within a context of conceptions of "force". The Post-Intervention interview analysis focused on the elicitation of groupings of conceptions and alternative conceptions about friction and frictional phenomena within the context of the depicted instances of the interview cards. A comparison of the conceptions elicited in the pre-intervention interviews with those of the post-intervention interviews has revealed some aspects of conceptual change which are illustrated with the analysis of two cases of children in each study.

This inquiry has found that children can develop conceptions of friction within its "surface roughness" approximation. The interlocking of the roughness of surfaces appears for them to be a plausible and fruitful explanatory framework to describe and interpret friction and frictional phenomena. Some of children's preconceptions about "grip", the role of the nature of surfaces in contact and the role of gravity, or the force of weight influencing frictional phenomena, appear to be retained and enhanced throughout the teaching interventions by adding new characteristics or properties or by extending their frames of reference for different contexts. In both studies, there appear to be similarities in the conceptions elicited about frictional phenomena and the way conceptual change occurs, despite some language differences, which appear to be reflected on the construction of children's propositional statements.

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General introduction

This inquiry aims to:

- elicit children's conceptions about friction and frictional phenomena and to deepen our understanding about such conceptions
- examine how certain teaching interventions influence the construction of children's conceptions and the process of conceptual change, and
- highlight and identify some aspects of children's conceptual change in reference to their conceptions about friction and relevant frictional phenomena

The subsidiary aims of the inquiry are:

- to investigate analyse and interpret children's conceptions before and after a teaching intervention on friction and frictional phenomena
- to conduct a teaching intervention that will elicit and challenge children's conceptions about friction and frictional phenomena and promote conceptual change through investigative work and negotiation of meanings
- to use a comparison between children's conceptions before and after the teaching intervention in order to highlight some aspects of their conceptual change
- to identify some similarities and differences in the conduct, analysis and interpretation of the research data from the studies in England and in Greece

In other words, it seeks to investigate and identify how children's naive or intuitive preconceptions change and become more elaborated and advanced conceptions. The inquiry is guided by a constructivist view of teaching and learning which is described in Chapter 1. Teaching interventions are organised in order to help children to view frictional phenomena in different ways and to change their conceptions about friction. The "surface roughness" theory of friction is the approximation which is used as a conceptual framework for teaching and learning about frictional phenomena (cf. Chapter 2).

The concept of friction has been chosen because it can be incorporated in a broader thematic area of learning about the of concept of force, it can be investigated in the classroom with simple experimental arrangements and it is a national curriculum topic for primary science in both of the countries involved (England and Greece). In this sense, the concept of force has been seen as a "push" or a "pull" in a certain direction which may also affect the kinetic condition of an object. Friction is also seen as a force with particular effects in the interface of two surfaces in contact. Moreover, it appears to be a single key concept with rather narrow limits of reference, which seems to be proper for a holistic approach of the notion of conceptual change that is attempted in this inquiry.

The empirical work for this inquiry took place in two educational settings, one in England and one in Greece. The study in England was conducted with a Year 6 in a primary school at Nottinghamshire, whereas the study in Greece was conducted with an E' Grade of a primary school in Rethimno, Crete.

A modification of the Interview-About-Instances technique has been used as a research method to probe and elicit children's conceptions and conceptual change, whereas some assessment techniques have also been used to represent children's conceptions from a different perspective and to cross-examine them with the interview data (cf. Chapters 3, 4, 5).

Some further issues and considerations that have emerged from the conduct of this research inquiry in two countries, two educational systems and two languages are discussed in the last chapter, together with methodological considerations, some limitations for both substance and scope and a self-critique.

CHAPTER 1

A theoretical framework for teaching and learning as conceptual change

> 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 theoretical perspective, they

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

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.).

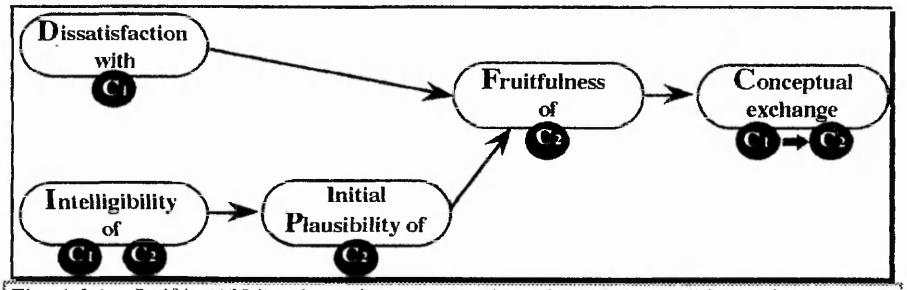


Fig. 1.2.1: Swift's (1984) schematic representation of the four conditions of conceptual change as they have been expressed by Posner et al. (1982) in combination with Hewson's (1981) notion of *conceptual exchange*.

[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).

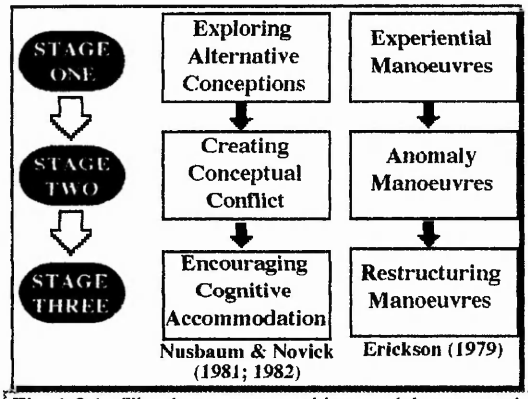


Fig. 1.3.1: The three-stage teaching models proposed by Nussbaum & Novick (1981, 1982) and Erickson (1979) (Osborne & Freyberg, 1985, p. 103)

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).

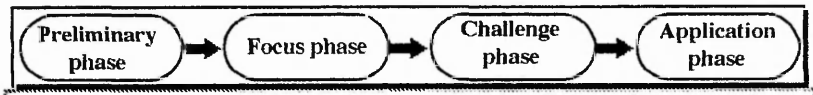


Fig. 1.3.2: The 'generative learning' model of teaching (Osborne & Freyberg, 1985)

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.

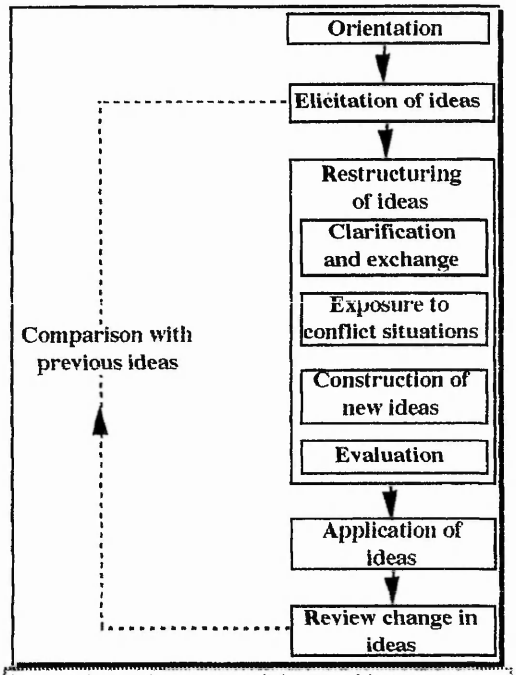


Fig. 1.3.3: A constructivist teaching sequence presented by Driver & Oldham (1986) or Driver (1988, 1989).

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).

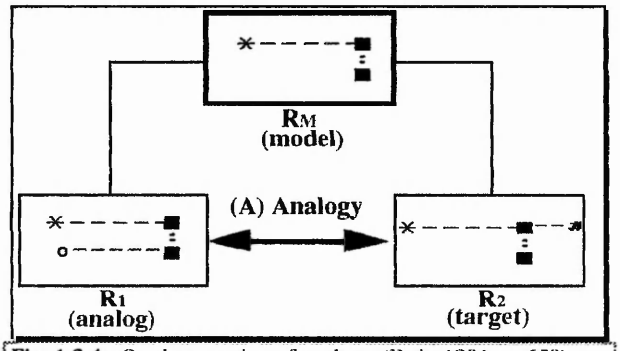


Fig. 1.3.4: On the meaning of analogy (Duit, 1991, p. 650)

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 $\mathbf{R}_M$,

[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.

represents this structural identity, thus $\mathbf{R}_M$, is called a model (Duit, 1991, p. 649). The 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

[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.

fruitful for the learners to find out how it could possibly make sense (Duit, 1991, p. 667). Gowin (1983) observes that:

> 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.

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[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.

Another reason could be that the learners are not familiar with the analog domain (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).

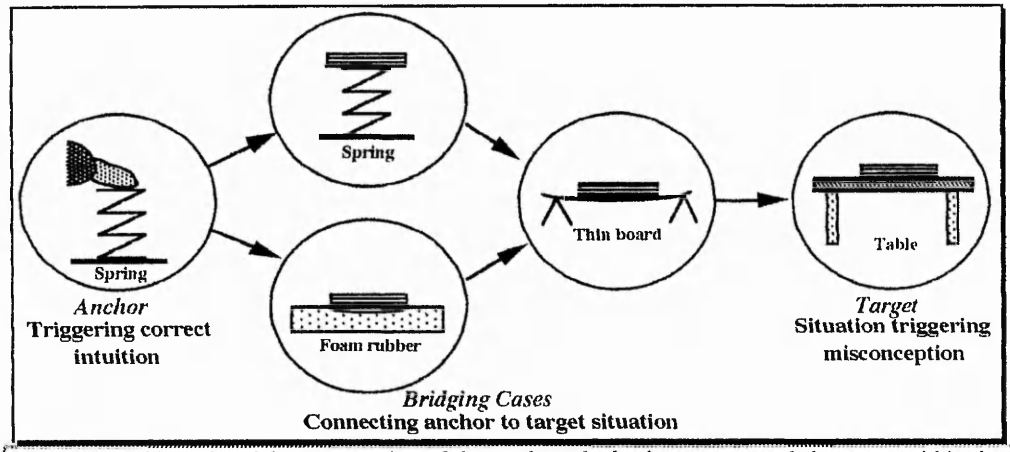


Fig. 1.3.5: This a pictorial representation of the *anchor*, *the bridging cases* and *the target* within the "bridging analogies approach" (Clement, 1987; Brown & Clement, 1989; Brown, 1994).

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).

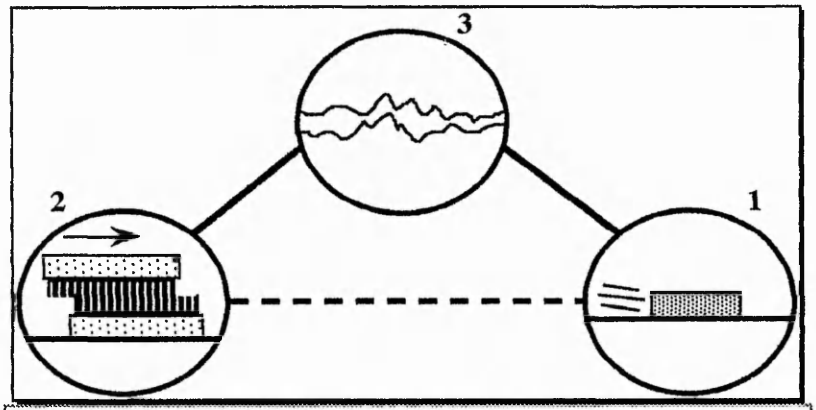


Fig. 1.3.6: An analogy diagram, where the *target situation* is a sliding shuffleboard puck (**1**), the *anchor* is that of two slightly intermeshed hairbrushes (**2**) and the '*microscopic model rather than the analogy*' is a magnified view of the puck and the floor (**3**) (Brown & Clement, 1989,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

CHAPTER 2

Concepts of friction

> Concepts, like individuals, have their histories, and are just as incapable of withstanding the ravages of time as are individuals.
>
> Kierkergaard, S. *The Concept of Irony*[1]

2.0. Introduction

In this chapter, there is an attempt to present and analyse concepts of friction and related phenomena, within a historical perspective and a context of contemporary physics. This aims to highlight some phases or episodes of conceptual change related to 'friction', throughout the consensus of the evolution of human thought. It is suggested that this analysis provides helpful insights for interpreting children's ideas on frictional phenomena. An etymological analysis of friction in two languages (English and Greek) is also considered. In the last section of the chapter, there is a review of research into children's alternative ideas or conceptions of friction, aiming to provide a context of children's meanings for relevant terms.

2.1. An etymological analysis of terms

Before proceeding with the historical presentation of the concept of friction, it is considered important to refer to the terms themselves, in order to clarify the nomenclature of the concepts under investigation. In this sense, an etymological analysis of the words should come first. This is not an easy task, bearing in mind the two different languages (English and Greek) involved in this inquiry. But, as it is suggested here, the etymology of some words used in the two languages to describe friction and frictional phenomena seems to have a common basis.

In reference to the etymology of the word **friction,** the Oxford dictionary (1989) states that, friction is a noun that derives from the verb "**fricate**", which originates from the Latin verb "***fricare***", which means "**to rub**"[2]. The dictionary also gives

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[1] As quoted in: **Toulmin S.** (1972) Human Understanding, Oxford: Clarendon Press, p. VI.
[2] The Oxford English Dictionary, 1989, p. 190.

several definitions of the term such as: "*the action of chafing or rubbing*", or "*the rubbing of one body against the other; attrition*", or "*the resistance which any body meets in moving over another body*" (ibid.). A number of derivatives, either from the verb "fricate" or from the noun "friction", are also quoted, such as: *frication, fricative and fricatory; frictionable, frictional, frictionary, frictionize and frictionless* (ibid.).

The above etymological analysis of the word "friction" doesn't seem to have a clear link with the Greek language. However, "friction" is not the only word that is used in the nomenclature of physics that refers to phenomena of bodies rubbing relatively to each other. The Oxford English Dictionary defines "*the branch of science and technology concerned with interacting surfaces in relative motion and with associated matters (such as) friction, wear, lubrication and the design of bearings*" as "***tribology***" (p. 504).

"Tribology", which is of course a technical term, is a composite word of two components [f. Tribo- + -ology]. The first component "tribo-" comes from the ancient Greek word ***"τρίβος"*** [tribos] which is a noun and it means "rubbing", or metaphorically something that is "trivial" (Dimitrakos, 1964, pp. 7274-7275). The second component "-ology" comes from the ancient Greek word "***λόγος***" [3][logos] and in this case it denotes "*the science or study which a person is concerned, or that deals with a certain subject*" [4]. Here, of course, it is the first component "tribo-" which is of particular interest, not simply because it is of Greek origin and the main component for several other composite words describing frictional phenomena (such as triboelectricity, triboelectrification and triboluminescence), or the derivatives of tribological and tribologist, or even the specialised field of physics dealing with frictional phenomena called "**tribophysics**"[5]. But, it is more important to point out that in modern Greek it is the word "***τριβή***" [tribi] that can be translated into English

[3] It is a frequent component for many other words of Greek origin that can be found in English language, such as *pathology, phonology, psychology* etc.

[4] The Concise Oxford Dictionary of English Etymology (1986), Oxford University Press, p. 270.

[5] Most of these words constitute part of the nomenclature of this specialised field of Physics.

as "friction". "***Τριβή***" means "*the action of rubbing*" [6] (Dimitrakos, 1964; p. 7274) and it is a noun which derives from the verb "***τρίβω***" [tribo] which can be translated as "rub" (active voice).

In this sense, it could be claimed that in Greek there is a more profound and explicit connection between the verb (***τρίβω***) and the noun (***τριβή***), because of their common root ("***τριβ-***") and origin, or at least, this can be assumed on a lexical basis of analysis. While in English, the words "**rubbing**" and "**friction**" do not seem to have an explicit connection, at least on a lexical basis, because of their different origins and denotations. Hence, in the Greek language, one word (***τριβή***) appears to have a semantic link with both "friction" and "rubbing", whereas in the English language there doesn't seem to be a linguistic clue to link these two concepts with one reference word.

But, on the other hand, if we etymologically co-examine the two fundamental terms that are under consideration here, "**friction**" in English and "**τριβή**" in Greek, we can observe that they both derive from verbs that have the same meaning, although it is expressed in different words because of the discrete nature of the two languages. In these terms, the Latin verb "***fricare***" and the Greek "***τρίβω***", both have the same meaning which can be expressed in English with the verb "**to rub**". Thus, although different words are used in English and in Greek in order to describe phenomena of friction, the same underlying meaning can be revealed in both languages, once more on a lexical basis of analysis. It is more likely that these differences may play an important role in the learners' construction of conceptions about friction and frictional phenomena. This inquiry searches to identify such differences.

These language issues will be considered again in the following chapters. A presentation of the concept of friction within a historical perspective of the physical science comes next.

[6] The translation of the entry is mine.

2.2. A historical presentation of friction

People must have been aware of the existence of friction ever since they tried to push, pull or drag loads on the surface of the ground. This could be located rather early in human history. Although at that time people could not probably give some sort of "scientific" explanation of the frictional phenomena they had to confront, we have certain indications that they did try to reduce friction in order to move loads with greater ease. This was mainly achieved by rolling rather than sliding wherever it was possible and it was certainly happening at least 5000 years ago as our knowledge of the history of the wheel shows (Faulkner, 1974).



Fig. 2.1: Transport of a statue by a sledge. A mural painting from a tomb at Saqqara, Egypt, circa 2400 BC (Faulkner, 1975, p. 34).

There were instances that the loads were too heavy to be carried on wheels, as in the case of the ancient Egyptians, who were trying to slide huge alabaster colossi that weighed about sixty tonnes. They were using sledges and they were lubricating the surfaces of the sledge and the ground which were in contact. The ground was often covered with wooden boards to avoid the sinking of the sledge in the sand (see fig. 2.1). The lubricant, presumably water, animal fat or oil, was being poured in front of the runners of the sledge[7]. Evidence of the use of a lubricant to reduce friction and wear has also been found on an axle of a chariot dated at about 1400 BC in the tomb of Yusa and Thuiu (Faulkner, 1974, p. 35).

[7] Notice in **fig. 2.1** the curved shape of the runners. Their rounded leading edges allowed the lubricant to be forced beneath them and as a result reduce friction (Faulkner, 1975, p. 35).

The classical philosophers such as Aristotle (384-322) left comments showing that the existence of friction and the usefulness of lubricants were common knowledge among the ancients (Bowden & Tabor, 1973, pp. 9-10). Aristotle in *Mechanica* [Μηχανικά][8] dealt with various mechanical problems, although special interest is often drawn on those problems concerning the circle, the levers, the rolling of wheels and the solutions that were proposed (Hett, 1936, p. 329).

Although we have some indications of small but significant pieces of knowledge concerning frictional phenomena, it could be claimed that nothing of "scientific" nature was undertaken until approximately 2000 years later, when Europe was under the influence of the Renaissance (Bowden & Tabor, 1973).



Fig. 2.2: Leonardo Da Vinci; a self-portrait (MacCurdy, 1956).

It was in the middle of the fifteenth century when Leonardo da Vinci (1452-1519) performed experimental work on friction. Leonardo presented his work in a mass of fragmental notes of uncertain date, repeating, completing and often contradicting one another (Taton, 1964). These notes were frequently accompanied with detailed and very descriptive drawings and various plans of machines and engines, that had a rather geometrical and proportional form (Richter, 1952).

Leonardo's mechanics were influenced by Aristotelian ideas as they were developed in various texts[9] (Cooper, 1935, p. 72 and Taton, 1964, p. 86). Leonardo wrote about friction, experimented on frictional phenomena by sliding blocks of wood on wooden boards or inclined planes and deduced the two basic laws of friction, two hundred years before Newton had given a clear definition of force (Bowden & Tabor, 1973, p. 11). About the nature of friction he suggested that:

> Friction is divided into three parts: these are simple, compound and irregular.

[8] It seems rather certain that this collection of 'mechanical problems 'is not the work of Aristotle, though probably it is the product of the Peripatetic School written somewhere in the years of 369-322 BC (Hett, 1936 and Taton, 1964)

[9] Such as Aristotle's *Physics*, *De Caelo* and *Mechanica*.

> ***Simple friction*** is that made by the thing moved on the place where it is dragged. ***Compound friction*** is that which the thing moved makes between two immovable things. ***Irregular friction*** is that made by the wedge of different sides.
>
> E. 35 r.[10]

He also wrote that:

> The action of friction is divided into parts of which one is simple and all the others are compound. Simple is when the object is dragged along a plain smooth surface without anything intervening; this alone is the form that creates fire when it is powerful, that is it produces fire, as seen with water-wheels when the water between the sharpened iron and this wheel is taken away.
>
> The others are compound and are divided into two parts; and the first is when any greasiness of any thin substance is interposed between the bodies which rub together; and the second is when other friction is interposed between this as would be the friction of the poles of the wheels. The first of these is also divided into two parts, namely the greasiness which is interposed in the aforesaid second form of friction and the balls and things like that.
>
> Forster II 131 v.

In Leonardo's *Notebooks* we can also find drawings that describe his experiments on friction (see fig. 2.3 and 2.4).

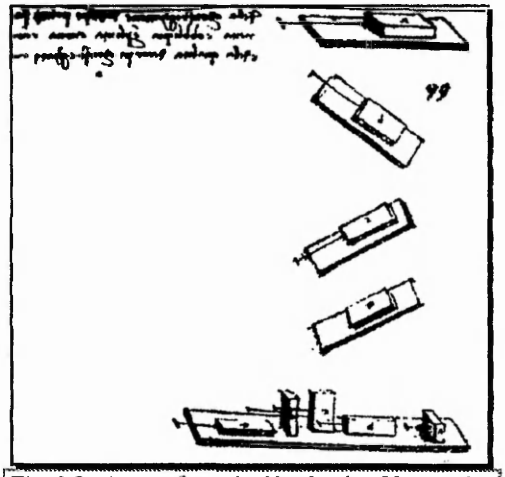


Fig. 2.3: A page from the *Notebooks* of Leonardo da Vinci showing the experiment arrangement by which he showed that friction is independent of the size of the surfaces making contact (Bowden & Tabor, 1973, p. 11).

His two empirical laws of friction were stated as follows:

> **Friction produces double the amount of effort if the weight is doubled.**
>
> Forster III 72r.

> **The friction made by the same weight will be of equal resistance at the beginning of its movement although the *contact may be of different* breadths or lengths.**
>
> Forster II 132 v.

He observed that friction depends on the nature of the surfaces in contact and he argued that:

> If you desire true knowledge of the quantity of the weight required to move the hundred pounds over the sloping road, it is necessary to know the nature of the contact which this weight has with the smooth surface where it produces friction by its movement, because different bodies have different kinds of friction; ...
>
> Forster II 87 r.

[10] All of the following original references on Leonardo's writings are from **MacCurdy, E.** (1956) *The Notebooks of Leonardo da Vinci*, London, Jonathan Cape, Vol. I, pp. 447-580. The number at the end of each excerpt refers to the original sources as they are given in MacCurdy's presentation.

Bowden & Tabor (1973) contend that he even produced a quantitative result from his experiments, that "*every frictional body has a resistance of friction equal to one quarter of its weight*" (p. 12). For rough surfaces of wood that come to contact and are slid one relative to the other, this seems to be a fair observation.[11]

He was also aware of the role of lubrication and he suggested that:

> All things and everything whatsoever however thin it be which is interposed in the middle between objects that rub together lighten the difficulty of this friction.
>
> Forster II 132 r.

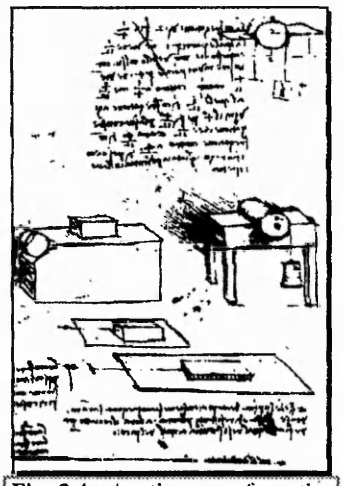


Fig. 2.4: Another page from the *Notebooks* of Leonardo shows experiments with blocks of wood sliding on tables, connected with ropes passing over pulleys and slid with the aid of weights (Faulkner 1974, p. 20).

Leonardo's work on friction and its conclusions were forgotten and only 200 years later interest arose again in this area, together with the great epoch of classical mechanics (Bowden & Tabor, 1973, p. 12). The first systematic studies on friction were carried out in France by members of the Royal Academy of Sciences. In 1699, the architect and scientist Guillaume Amontons (1663-1705) published a paper on friction, in *Mémoires de l' Académie des Sciences.* That paper was entitled "On the Resistance Generated in Machines" and it is the first known study on the question of losses caused by friction in machines, more precisely in the design of turbine water wheels. In the beginning of his paper, Amontons, made a rather elegant plea for the study of friction:

> Indeed of all authors who have written on motive forces, there is perhaps not one who has paid sufficient attention to the effect of friction in machines and to the resistance caused by the stiffness of ropes, or who has given us rules for knowing the effect of either one and for reducing them to mathematical formulas. (as quoted in Gillmor, 1971, 120)

Eighteenth-century authors were unanimous in according Amontons credit for the first studies of friction. None mentions any studies by the ancients or by Leonardo, whose *Notebooks* were unknown to them, until the nineteenth century (Gillmor, 1971,

[11] In modern terms we would say that the **coefficient of sliding friction** of wood over wood is $^1/_4$ which is a fair approximation for unplane wooden surfaces in contact.

p. 118). Nevertheless, after testing and sliding several blocks in all possible orientations, Amontons went on to rediscover the laws of friction that were originally deduced by Leonardo da Vinci. (Bowden & Tabor, 1973).

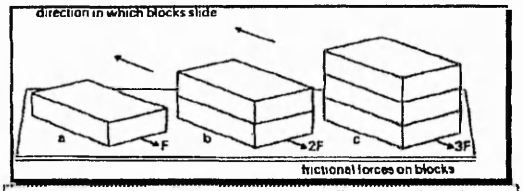


Fig. 2.5: A representation of the first empirical law of friction. If each of the blocks added in (b) and (c) situations have the same weight with (a) then friction would double and triple respectively (Faulkner, 1974, p. 20).

The first law, that frictional force is proportional to the force pressing the surfaces together when they are in relative motion to each other, was accepted by the Academy without any doubts (see fig. 2.5).

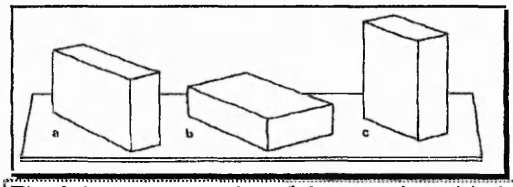


Fig. 2.6: A representation of the second empirical law of friction. These are three identical blocks in different orientations (Faulkner, 1974, p. 19).

On the contrary, the second law, that friction is independent of the area of contact, provided that the force between the surfaces and the nature of surfaces remain the same (see fig. 2.6), was viewed with astonishment and scepticism by the Academy (Bowden & Tabor, 1973 and Faulkner, 1974).[12] Their senior academician Phillipe De la Hire (1640-1718) was instructed to repeat Amontons' experiments in order to verify or falsify his conclusions. This he did and announced that Amontons' conclusions were valid, verifying his two empirical laws of friction which have remained with us to this day as a very good approximation of frictional phenomena. These laws refer to rough surfaces that come to contact (i.e. wood over wood) and for "normal" speeds (speeds which are not at high or low extremes) of sliding one surface over the other (Bowden & Tabor, 1973, p. 14 and Ohanian, 1989, p. 136). The kind of surfaces, that Amontons experimented with, were also rough and he suggested that friction was the

[12] The second "law" of friction would seem plausible only if *"the macroscopic area of contact is the same for all positions of the block, and this is indeed the case. With the largest face down, there are a relatively large number of relatively small area contacts supporting the load; with smallest face down there are fewer contacts (because the apparent contact area is smaller) but the area of individual contact is larger by just the same factor because of the higher pressure exerted by the up-ended block on this smaller number of contacts supporting the same load"* (Halliday Resnick, 1981, p. 100).

result of the work done in lifting one surface over the roughness of the other, or even overcoming or breaking off this roughness. His belief construed, somehow, a "**surface roughness theory**" of friction which was generally accepted, approximately during the following century, when most of his contemporary scientists maintained these ideas as a convenient explanation for certain phenomena (ibid.).

However, John Theophilus Desaguliers (1683-1744), an English scientist of French origin, who taught physics at Oxford for several years, put forward a rather different view of the mechanism of friction. In 1734 he published his book *A Course of Experimental Philosophy*, where he experimented with metal bodies and observed that:

> ... the flat surfaces of metals or other Bodies may be so far polish'd as to increase Friction; and this is a mechanical Paradox: but the reason will appear when we consider that the Attraction of Cohesion becomes sensible[13] when as we bring the surfaces of bodies nearer and nearer to Contact. (A Course of Experimental Philosophy, London, 1734, p. 182; as quoted in Bowden & Tabor, 1973).

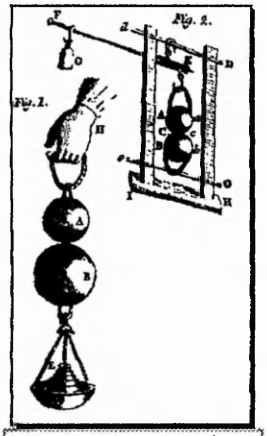


Fig. 2.7: Drawings from a paper published by Desaguliers on the cohesion of lead (Bowden & Tabor, 1973, p. 15).

He then went on to consider the surface roughness theory of friction by referring to his earlier work on the cohesion of lead (see fig. 2.7). He described one of his experiments with leaden balls as follows:

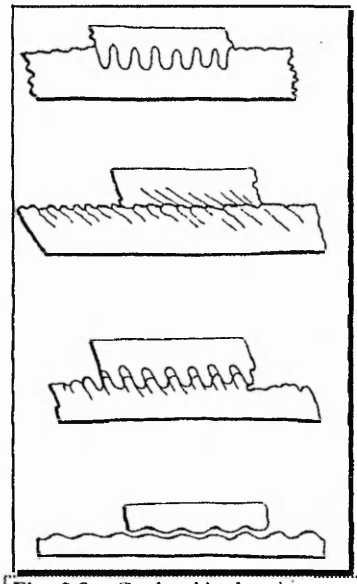
> I took the Leaden Balls ... and having from each of them cut off a Segment of about $^{1}/_{4}$ inch in Diameter, I pressed them together with my Hand, with a little Twist, to bring the flat parts to touch as well as I could. The Balls stuck so fast, that ... the lower one was sustained though loaded with the Scale S and the Weights E which amounted 16 pounds. A little more Weight added separated them and, upon viewing the touching surfaces, it appeared that they did not exceed a Circle of $^{1}/_{10}$ Inch Diameter ... (Bowden & Tabor, 1973; p.16).

Although Desaguliers realised that cohesion plays an important part in friction he could not see how that could explain the laws of friction; hence, he didn't fully develop his ideas on cohesion and stayed within the framework of the "surface

[13] Faulkner (1974) suggests that Desaguliers means 'noticeable' here.

roughness theory" of friction (Faulkner, 1974 and Bowden & Tabor, 1973). Nevertheless, Desaguliers' work was important because it was a challenge to Amontons theory and it presented, as a possibility, the molecular origin of friction (Gillmor, 1971, p. 126).

It was Coulomb (1736-1806) who systematically organised his research, considered all of these conjectures within a synthetic approach and managed to pull them together (Gillmor, 1971). In 1781 he published his work on simple machines, friction and other related issues in *Théorie des machines simples* which won him the Academy award. He investigated both static and sliding friction, the friction in bending of cords and in rolling (Halliday & Resnick, 1981, p. 99). He was committed to a unique, inquisitive, wide-ranging type of experimentation which enabled him to develop a series of two-term equations: 1) a constant term usually attributed to cohesion (*cohérence*) or a surface film (*duvet*) and 2) a variable term which could be time, normal force, velocity, or other parameters (Gillmor, 1971, p. 126).



Fig, 2.8: Coulomb's drawings on the interlocking of surface roughness (Bowden & Tabor, 1973; p. 17)

Coulomb recognised that most of the surfaces Amontons, his contemporaries and partly himself had worked with were not smooth. On the contrary, they were rather rough, with asperities visible even to the naked eye. When two such surfaces are placed together, one against the other, it looks as if the roughness of one is getting into the roughness of the other; somehow, they interlock with each other. Coulomb (1781), in *Théorie des machines simples* made some drawings to illustrate his ideas on the interlocking of surface roughness (see fig. 2.8). One could say that this interlocking resembles to the interlocking bristles of two brushes that are placed one against the other (Bowden & Tabor, 1973, p. 18).

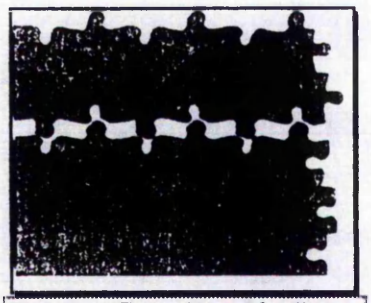


Fig. 2.9: Two pieces of a jigsaw puzzle, just before they fit into each other.

Conceivably, a better analogy for the interlocking roughness of two surfaces, could be two pieces of a jigsaw puzzle that fit together once they are put into contact[14] (see fig. 2.9). The question that now arises, is whether this "surface roughness theory" of friction can actually provide an adequate explanation for the phenomenon of sliding friction. The phenomenon could be examined more closely, through the goggles of this theory.

As Bowden (1950), quite lucidly described it in a BBC broadcast, "*putting two solids together is rather like turning Switzerland upside down and standing it on Austria-the area of intimate contact will be small*" (Bowden & Tabor, 1973, p. 47).

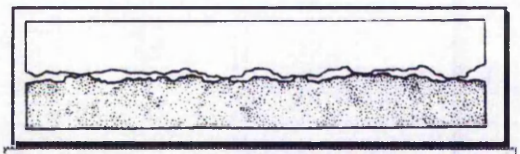


Fig. 2.10: Two rough surfaces placed one on top of the other; a closer look (Faulkner, 1974, p. 21).

In analogous terms, someone could say that the minute "mountains and valleys" of the upper surface, fit or to some extent they interlock, with the equivalent parts of the lower surface, at those distinct points of contact. Thus, the overall interface[15] of contact is a lot smaller than the one which could be originally considered, bearing in mind a notion of absolute surface contact (see fig. 2.10).

According to "surface roughness theory", overcoming sliding friction could be explained in terms of the effort that has to be exerted in the sliding of the asperities of the upper surface up the slopes and over the top of the asperities of the lower surface. This would mean that the upper surface would have to be raised slightly, in order to let its peaks slide over the peaks of the lower surface. The heavier the upper body the greater would be the effort needed to raise it in this way, thus friction is proportional

[14] This analogy will be reconsidered in the following chapters as a teaching analogy in terms of an explanatory representation of frictional phenomena.

[15] *Interface* is a surface forming a common boundary between two regions.

to the weight of the body (first law). Consequently, the effort to lift the upper body would depend only on its weight, not on its area, thus friction is independent of the area of contact (second law).

At first sight, this mechanical surface-asperity explanation seems to be a plausible one. However, if it is considered more carefully, it fails to explain what happens when the surface of the top body has risen over the peaks of the asperities of the surface of the lower body. At that instant, does it start to move forward and down the other side of the slope on its own accord? This would mean that the effort exerted previously in overcoming friction when sliding up the slopes of the lower surface, would now be restored and somehow *help* in sliding down the other side of the slope. But, this doesn't actually happen. Friction, in most cases, opposes the motion, it doesn't set things going or help them along.

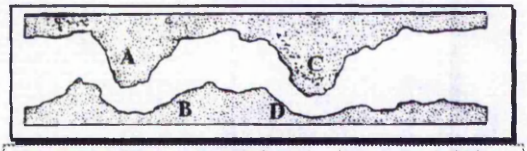


Fig. 2.11: The upper surface is sliding from left to right. This is a magnified pictorial representation of

Fig. 2.11: The upper surface is sliding from left to right. This is a magnified pictorial representation of the phenomenon at a certain instant (Faulkner, 1974, p. 21).

In reality and through a macroscopic approach, when two surfaces are in contact and it is attempted to slide one over the other, there are thousands of asperities going over slopes and the other way round. Of course, these slopes and asperities are not all identical and the whole phenomenon does not happen at all parts of the surfaces simultaneously. Parts of the body may be sliding up roughness slopes but other parts will be sliding down respective slopes somewhere else, or at a later instant. At a certain instant, asperity **A** can be sliding up **B** slope and at the same time asperity **C** can be sliding down **D** slope (see fig. 2.11). Consequently, the surface of the upper body would, in general, neither rise nor fall. Therefore, this explanation of the phenomenon of sliding friction, although a plausible approximation, doesn't seem to be generally adequate.

Naturally, someone could counter the argument that effort is similarly being used up when the asperities of a surface get to the top edge of the slopes of the other surface

and consequently they start sliding down with a burst, bending down these parts of the surfaces. Thus, all the effort supposedly *restored* in sliding down the slopes, is actually *used up* in terms of deformation work during the impact at other parts of surfaces. If such a view is adopted, it seems rather certain that we have moved away from the "dragging-up-the-roughness model" and we have approached **a deformation mechanism** (see fig. 2.12), which is involved in sliding friction (Bowden & Tabor, 1973, p. 22).

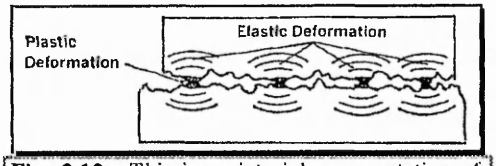


Fig. 2.12: This is a pictorial representation of elastic and plastic deformation and the respective regions of the surfaces that it occurs (Bowden & Tabor, 1973, p. 65)

This could be described as a mechanism of *plastic deformation*, occurring at the regions of actual contact where friction junctions are formed, but also of *elastic deformation*, occurring at the surrounding regions, which are released when the load is removed. As a result, the friction junctions are broken and small pieces of the surfaces are sheared apart and/or welded on one of the surfaces (Bowden & Tabor, 1973, p. 65). Relatively recent work and experimentation on friction has shown that the true area of contact between two surfaces depends not only on the geometry of these surfaces (as it was considered by most of the scientists of the French Academy), but also on the way the individual asperities are deformed (Bowden & Tabor, 1973, p. 23).

On the other hand, if one accepted a "**cohesion theory of friction**", it would consequently mean that larger surfaces would create more friction, due to greater cohesion at the touching points of a larger interface. Thus, sliding friction would depend on the size of the surface of the bodies that are in contact. This would mean that friction would double, if one doubled the contact regions, or in other words, if one doubled the area of contact. As we have seen so far, this didn't seem to be the case with the sliding friction of rough surfaces (Bowden & Tabor, 1973).

Coulomb criticised the neglect of deformation mechanisms in previous work. At the beginning of his memoir (1781) he noted the five most important parameters in static and dynamic (sliding) friction:

- the nature of materials and their surface coatings
- the extent of surface area
- normal force[16]
- the length of time that the surfaces remain in contact before motion begins (time of repose)
- the relative velocity of the contact surfaces. (Gillmor, 1971, p. 132)

Even though Coulomb attributed some role to cohesion concerning frictional phenomena, he could hardly believe that it could be the main cause. He seemed to believe that friction was due to the work done in dragging one surface over the roughness of the other (Bowden & Tabor, 1973, p. 18). Thus, although he considered several aspects of frictional phenomena, it seems that he stayed within the framework of "surface roughness theory" of friction (Gillmor, 1971).[17]

Coulomb and his eighteenth century contemporaries did not consider energy loss when they referred to the mechanism of friction. It was known and often stated that friction resulted in heat or in loss of motion, but no one really introduced these into a theory (Gillmor, 1971, p. 137). John Leslie (1766-1832), in a study of the nature of heat (1804), first investigated these problems and introduced the idea of a deformation wave which was produced by the interacting surfaces and travelled ahead of the contacting areas in the direction of propagation. He claimed that the resulting process was responsible for the generation of heat (ibid.). Today this is considered in terms of plastic deformation and hysteresis loss.

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[16] When a body is pressed against a surface, the body experiences a force that is perpendicular to the surface. The force is called the **normal force N**, the name coming from the mathematical term *normal* which means "perpendicular" (Halliday, Resnick & Walker, 1993, p. 106).

[17] Nevertheless, Coulomb's work on friction remained a standard of theory and experiment for a century and a half, until the advent of molecular studies of friction in the twentieth century. Kragelsky and Schedrov authors of the only book on the history of friction, state: "Coulomb's contributions to the science of friction were exceptionally great. Without exaggeration, one can say that he created this science" (as quoted in Gillmor, 1971, p. 136)

In conclusion, the "surface roughness theory" of friction receives, at least to an extent, some support from every day experience and intuition. It seems plausible that rough surfaces should have more friction than smooth surfaces. But, as Desaguliers pointed out, our intuition could be deceiving, as for instance in the case of polished metals in contact where friction can be highly increased. In fact, cohesion can play a major part in the sliding friction of metal surfaces, particularly if they are fairly clean when they come to contact (Bowden & Tabor, 1973, p. 23). Moreover, very smooth surfaces, like cleaved mica, which is smooth to within one atomic diameter, give friction at least as great as that of ordinary surfaces. It is such paradoxical phenomena that challenge our intuition and promote our investigation.

2.3. A perspective of friction in contemporary terms

It is a matter of common knowledge and experience that if a book is placed on a table it stays at that particular position. If we wish to slide it across the table, we can push it until, at a certain instant, the push is powerful enough to move it. We can easily observe that once the pushing force is removed, the book will slide for a certain distance whilst is slows down and eventually stops somewhere on the table. This is due to a frictional force exerted by the table top on the bottom of the sliding book which acts to slow it down and eventually bring it to rest. If we wish to move the book across the table with a constant velocity, we must push it or pull it across by exerting a steady external force to it, just large enough to be equal and opposite to the frictional force.

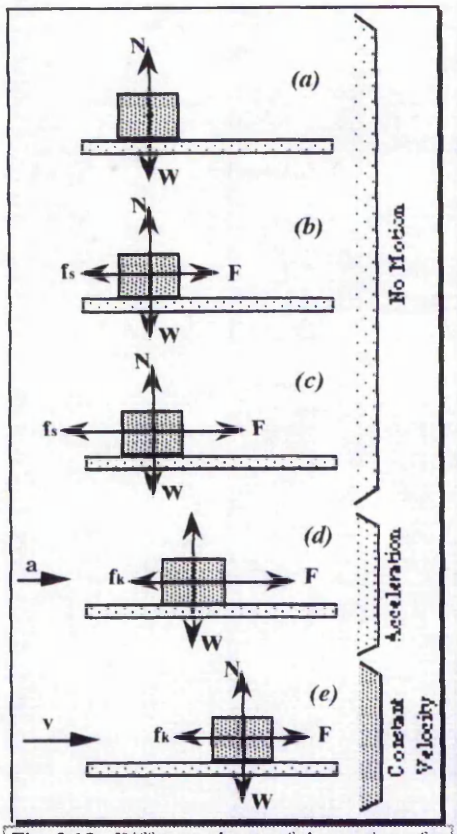


Fig. 2.13: Different phases of the motion of a block resting on a tabletop with the respective force diagrams.

One could examine more carefully a block which is resting on a tabletop, in order to describe some phases of its motion in detail (see fig. 2.13). In *(a)*, the block is stationary on the tabletop, its weight is **W** and is balanced by an equal but opposite Normal force **N**. In *(b)* a force **F** is exerted on the block attempting to pull it on a direction from left to right. In response, a frictional force $\mathbf{f_s}$ arises pointing to the left, matching the magnitude of the force **F** that has been applied on the block. The force $\mathbf{f_s}$ can be defined as **static frictional force**. In *(c)* the block remains at rest, because while the applied force **F** is been increased, the static frictional force $\mathbf{f_s}$ also increases, till it reaches its maximum value, opposing the motion of the block.

However, at a certain instant, the magnitude of the applied force **F** increases to such a value that the block can no longer maintain its stationary position, it "breaks away" and it starts sliding on the tabletop. It accelerates and it moves from left to right, on the direction of the applied force **F** as it is shown in *(d)*. In this case, the frictional force, that opposes the motion, can be defined as **kinetic frictional force**[18], $\mathbf{f_k}$ (Halliday, Resnick & Walker, 1993, pp. 132-133).

Generally, the kinetic frictional force, which acts when there is relative motion of two surfaces that slide one over the other (as in the case of *(d)*), is less than the maximum static frictional force, which acts when there is no motion (as in the case of *(c)*).

[18] The term "kinetic frictional force" is treated as synonymous to the term "sliding friction" that was used earlier in this chapter.

Thus, if we want the block to move with a constant velocity, we usually have to decrease the applied force **F**, once the block begins to slide on the tabletop (op. cit.).

Apart from static and sliding friction there is also the friction which is involved in the rolling of objects (wheels, rollers etc.), namely "rolling friction". This kind of friction is considered as a 'special case' and it is presented in Appendix I, together with the 'drag force' experienced in liquids and a presentation of the above properties of friction in more abstract terms.

2.4. Approximations of frictional phenomena

Although frictional phenomena are complex, simple empirical "laws" are found to apply in many situations; in fact, this is what was presented earlier in this chapter. However we should not expect these laws to be of the same basic character as Newton's laws of dynamics or the law of gravitation. The "laws" of friction are only approximate descriptions of the way that matter behaves under some, but not all, conditions. When we lack a fundamental theory for a process or find a theory too complicated to use in practical situations, we are forced to rely on approximate or empirical descriptions. Hook's law of the force of a spring or Ohm's law of electric conductivity are such empirical laws. None of these empirical laws is valid for all circumstances, but each is sufficiently right for many practical applications.

In this respect, "the surface roughness theory of friction", "the deformation mechanism", or "the cohesion theory of friction" are only particular approximations of frictional phenomena and there are certain instances, within a variety of levels of conjectural claims, where one or the other can provide an adequate description, or even a plausible explanation. Furthermore, in a microscopic view, friction is basically "*an **electromagnetic force** acting between the surface atoms of one body and those of another*" (Halliday, Resnick & Walker, 1993, p. 133). This is another

approximation, at an atomic or molecular level, which seems to provide update, plausible and often fruitful descriptions and explanations of frictional phenomena.

Thus, we have a series of approximations, concerning friction and related phenomena, which have evolved and are still evolving in a pattern of a continual sequence within the context of human history. As Bachelard puts it, "*approximation is unachieved objectivation, but it is prudent, fertile objectivation which is truly rational because it is at once conscious of its insufficiency and its progress*" (Tiles, 1984, p. 129). It is these approximations which advance our understanding of "reality" and, in this respect, they help us to achieve progress in science. Consequently, paraphrasing Popper (1980), one can argue that "*the historical development of science is a process of step by step approximations*" (p. 268).

2.5. Concepts of friction in everyday life and a general context for teaching friction in primary science.

Friction is very important in our daily lives. Most people have experienced some problems when there is too little friction and the conditions are slippery. The interaction between the shoes and the floor makes it possible for us to walk. If there was no friction, walking or running wouldn't be possible or at least as we know it. We would probably have to use some kind of suction pads to move around, much like an octopus does. We wouldn't be able to ride a bike or drive a car because simply their wheels wouldn't go round, they would skid instead. We would not be able to hold a pencil and even if we managed to hold it, it wouldn't write on paper. Nails and screws would be useless or there wouldn't be any grip between a nut and a screw. Knots would come undone and the same would happen with the yarns in woven fabrics.

However, friction can also be a nuisance, especially in devices that move continuously. Approximately 20% of the gasoline of an automobile is wasted in

counteracting friction in the engine. Friction wears things out, like the soles of our shoes, the various tyres, the machinery of all kinds etc. Friction can cause excessive heating. If we rub our hands together, for instance, a small part of friction is used to rub off bits of skin, while the main part of the work done in overcoming friction appears as heat. This heating effect of friction could also have useful results like setting up a camp fire by rubbing pieces of wood together or lighting a match. Friction may also create sound as in the case of squeaking car tyres. This sound can sometimes be more pleasant or in fact it can be turned to music as the bow of a violin rubs skilfully against its strings.

These daily examples of frictional phenomena could provide a context for orientation when a teacher is about to engage herself in the teaching of respective concepts. If discussed with the children it would be anticipated that they could capture their curiosity and raise their interest in finding out more about these phenomena through further investigation and experimentation. It is not attempted, at this point, to raise the issue of "*what* should be taught" in a primary science classroom in reference to friction and related phenomena. The issue of the teaching content is a long, contradictory one, it is closely related to the official curriculum or textbook (wherever it exists) and here, it is considered further in the teaching interventions in chapters 4 and 5. At this point, it is sufficient to state the broader boundaries of this inquiry, in terms of the teaching content on friction. In other words, to provide some content objectives as expressions of "*ideas and items of knowledge to be achieved not through one set of activities but potentially of any of a variety, none having a greater priority than others*" (Harlen, 1978, p. 80). Thus, for the context of this inquiry in primary science education and bearing in mind the previous presentation and analysis of the concepts of friction, the following content guidelines could be put forward:

- Friction is a force which commonly opposes the motion of bodies (e.g. car, bike, block of wood sliding on a tabletop).
- Frictional phenomena could possibly be explained within the "surface roughness theory", using it as a precursory approximation, which has served humanity

successfully for a considerable time (this approximation can be highlighted and explained with the use of analogies, cf. § 4.2.5)

- Friction is proportional to the normal force and independent of the area of contact (investigations could be organised for this, e.g. various blocks of wood sliding on a tabletop)
- Factors that minimise and/or eliminate friction, such as: use of rollers or wheels, lubrication etc. (further investigation, using rollers, soap or oil could be organised with sliding bodies)

As it has already been discussed, children have their own understanding of the world and bring their own conceptions of various phenomena into science classrooms (cf. chapter 1). Thus, they have their conceptions about "rubbing", "gripping" and "slipping", and the effects of friction on moving bodies. Their prior knowledge needs to be seriously considered for the planning of investigations and other teaching and learning activities. Some of children's conceptions of friction follow in the next section.

2.6. Children's conceptions of friction

Although there are several studies which refer to learners' alternative ideas, conceptions (Leboulet-Barrell, 1976; McDermott, 1984; Twigger, et al. 1994; Thijs, 1992; Thijs & Bosch, 1995; Galili & Bar, 1992; Osborne, 1980; Gunstone & Watts, 1985) or frameworks (Watts & Zylberstejn, 1981; Watts, 1983a; Watts, 1983b) about the concept of *force*, there is only a limited number of studies on learners' ideas about the concept of *friction* (Stead & Osborne, 1980; Osborne, Schollum & Hill, 1981; Stead & Osborne, 1981).

Osborne, Schollum & Hill (1981) summarised their findings about learners' alternative conceptions or views of friction (children's science) which, as they claim, need to be changed to more generally acceptable views (scientists' science), and they presented them in the following Table:

Children's science ➡	**needs changing to** ➡	**scientist's science**
Friction is rubbing causing heat and wearing (p.21)	Friction can exist without surface wearing or heating up	Friction is a push or a pull (a sort of holding force)
Friction forces include pressure (or reaction) forces (p.24)	Friction forces are *not* pressure or reaction forces	Friction forces are holding forces *along* surfaces
Friction does not occur if there is no movement between surfaces (p.22)	Friction is *not* always associated with movement in the opposite direction	Friction forces can be in the same or opposite direction to the direction of motion[19]
Friction only occurs between solids (p. 26)	Friction is not just between solids	There can be friction between any combination of solids, liquids and gases

Table 2.1: Summarised findings on the concept of friction, from **LISP** (Learning in Science Project) (Osborne, Schollum & Hill, 1981, p. 11)

They used the Interview-About-Instances technique (cf. chapter 3) and some survey techniques (some kind of picture questionnaires) to elicit children's views about friction. One of the main features of children's responses was that the majority of the interviewees closely associated friction with rubbing, particularly the rubbing of two solid surfaces. Approximately 50% of the children in Years 8-11 specifically mentioned "rubbing" (op. cit., p. 21). Stead & Osborne (1981) claimed that the everyday association of rubbing with movement, wear, heat and pressure between the surfaces, leads to a number of 'non-scientific' views about friction.

Thus, some children seemed to accept that friction is a force while others had difficulties in stating it clearly. The idea the children seem to have of *more friction with greater movement,* leads to ideas about *more friction if something slides further*

[19] For example, in a case of a self propelled object, a person or a car accelerating, frictional forces, **in the direction of motion,** are producing the forward acceleration. Also there can be frictional forces present when there is no motion at all (emphasis and footnote in the original)

(Osborne, Schollum & Hill, 1981, p. 23). It was also claimed that learners often confused reaction forces with friction forces and that was a source of difficulty in teaching senior physics. Learners had difficulties in distinguishing between reaction forces that are at right angles to the surface and frictional forces which are directed along the surface (ibid.). Friction was closely associated with movement, in fact for few of the learners it seemed to be movement itself (Stead & Osborne, 1981, p. 53). Friction was also closely identified with energy, particularly with heat energy, which is not surprising, when friction is mostly associated with rubbing and movement. Some aspects of children's views about "friction" of liquids and gases were also investigated. A great number of the children interviewed believed that friction was only associated with the rubbing of solid surfaces, while some others believed that "friction" could occur in liquids (e.g. a swimmer in the water) but not in air (e.g. a sky diver) (Osborne, Schollum & Hill, 1981, p. 26).

2.7. A concluding remark

All the ideas included in this chapter have been very useful for the researcher in clarifying and sharpening the meanings of concepts throughout their history, but also through their use in the everyday language context. This, in its turn, has constituted a framework of conceptions which has helped the researcher to organise teaching interventions for the concept of friction. Hence, ideas from the experiments of Leonardo da Vinci, Amontons and Coulomb were used in the experiments with blocks of wood, which children attempted to slide on various surfaces of tabletops (cf. § 2.2. and § 4.2.5., § 5.2.3). Some ideas used for the explanation of phenomena and for the communication of conceptions shared between scientists, have been considered to be fruitful in representing analogous ideas for children. For example, Coulomb's drawings about the interlocking of two surfaces in contact, gave rise to the analogy of the two fragments of a jigsaw puzzle, which was used to represent the "surface roughness approximation" of friction in the teaching interventions (cf. § 2.2.,

p. 60). Moreover, the ideas presented in this chapter seem to provide an explanatory framework for helpful insights in the interpretation of children's alternative conceptions about friction and frictional phenomena, or at least the researcher has often used them as such, in the two studies that follow (cf. Chapters 4 and 5).

CHAPTER 3

Research Methods & Research Design

> ... at every moment he [the researcher] must have a working hypothesis, some theory, true or false, which he [the researcher] is seeking to check.
>
> ***J. Piaget*** (1929, p. 20).

3.0. Introduction

In this chapter there is an attempt to put this inquiry into a context of research methodology and to describe how the research was organised and conducted. This research project aims to deepen our understanding about children's conceptions of friction and frictional phenomena, to highlight some aspects of their change, and to explore how certain teaching interventions may help or hinder the whole process. Hence, the emphasis is on how children construct their conceptions and how they construe various phenomena using these conceptions as systems of explanation. The main issue is how reality is interpreted from the child's point of view, as a construct of the human mind. In this respect, the inquiry places itself within the *verstehen* tradition of educational research, with a focus on qualitative methodology due to the idiographic and holistic approach of the investigation (cf. § 3.1). The interview is used as the main research method, within a qualitative perspective, aiming to elicit, record and analyse idiosyncratic children's conceptions about friction and frictional phenomena (cf. § 3.2). The Interview-About Instances technique is used to collect data which refer to children's authentic utterances about certain depicted instances on the interview cards (cf. § 3.3). It is anticipated that this data collection technique will reveal information about children's conceptions and the various ways they use them to explain certain instances (cf. § 3.6). A scheme for the analysis and interpretation of data is presented (cf. § 3.8), and the chapter is concluded with the research design (cf. § 3.9).

3.1. Two research traditions and respective paradigms

Bassey (1995) gives a definition for research which derives from the teaching of Lawrence Stenhouse:

> ***Research is systematic, critical and self-critical enquiry which aims to contribute to the advancement of knowledge*** (p. 2).

In striving to make sense of the world, researchers seem to work in two research traditions, which reflect the ways in which they view reality: the *erklären* tradition, in which explanation is the goal and the *verstehen* tradition, in which understanding is the goal (Gilbert & Watts, 1983). The *erklären* tradition is *realist* in outlook and in this respect, reality is 'out there' irrespective of the observer. This reality can be discovered by people using their senses and their discoveries can be expressed through factual statements about people, events and about relationships between them (Bassey, 1995). Thus, within the *erklären* tradition, there is an empirical-inductivist view of knowledge, "with a firm belief in the value of a reductionist approach to phenomena, the use of replicable experimental methods in research for causal mechanisms" (Gilbert & Watts, 1983, p. 64). For the *verstehen* tradition reality is not 'out there' existing irrespective of people, but it is seen as a construct of human mind. There can be different understandings of what is real, since people construe the world in ways which are often *similar* but not necessarily the *same*. Thus, the *verstehen* tradition is *relativist* in outlook and it is influenced by post-inductivist views of knowledge "with a belief in the value of an holistic approach to the phenomena, seeking to perceive understanding as shown by the individual actors in any human situation without an overt pursuit for generalisations" (ibid.).

These two research traditions have become reflected in two paradigms for educational research. The term "paradigm" has originally been used as a major concept in Kuhn's (1970) epistemology, but here it can be defined as "the basic belief system or worldview that guides the investigator, not only in choices of method but in ontologically and epistemologically fundamental ways" (Guba & Lincoln, 1994, p. 105). Thus, **Paradigm I** follows the *erklären* approach and **Paradigm II** follows the *verstehen* approach (Watts & Gilbert, 1983). Some of their main characteristics can be identified in Table 3.1 below:

PARADIGM I *'Erklären Approach'*	**PARADIGM II** *'Verstehen Approach'*
Traditional	Non-traditional
Scientific	Artistic
Experimental	Naturalistic
Reductionist	Holistic
Prescriptive	Descriptive
Quantitative	Qualitative
Nomothetic	Idiographic

Table 3.1: Two paradigms for research in education and some of their main characteristics (Gilbert & Watts, 1983, p. 64)

The two paradigms are seen here as complementary, each with its own limitations in terms of scope and research methods. Powney and Watts (1987) take interview as an example of research method, to highlight such limitations and point out that:

> There are many occasions when the traditional survey research interview-with its emphasis on counting and statistical patterns-is inappropriate. Equally so, the ethnographic interview, with its own emphasis on rich data from a limited number of participants, cannot cope with producing answers to all questions (p. 182).

Guba and Lincoln (1985) had originally discussed their approach to the *verstehen* tradition as "naturalistic inquiry". Later on they refer to it as "constructivist paradigm" (Guba & Lincoln, 1985, p. 19), they characterise their methodology as "constructivism" and they point out that constructivist, interpretative, naturalistic and hermeneutical are all similar notions. Thus, their constructivist philosophy appears to be idealist; that is, they assume that what is real is a construction in the minds of individuals. It is also pluralistic and relativist in terms of multiple, often conflicting constructions. These constructions are all, at least potentially, meaningful and their "truth" is sociohistorically relative. Truth, appears to be a matter of best-informed and most sophisticated construction on which there is consensus at a given time. Hence, they claim that constructions are resident in the minds of individuals and "*do not exist outside of the persons who create and hold them; they are not part of some 'objective' world that exists apart from their constructions*" (Guba & Lincoln, 1989, p. 143).

Marton (1981a, 1986) and the school of *phenomenography* adopt a relational point of departure and distinguish between two perspectives through which we can see the world. In the *first-order perspective* which is the most commonly adopted, we orient ourselves towards the world and we make statements about it. In the *second-order perspective*, we orient ourselves towards people's ideas about the world (or their experience of it) and we make statements about people's ideas about the world (or about their experience of it) (Marton, 1981a). Although both perspectives are seen as complementary, it can be claimed that within a constructivist framework of ideas the *second-order perspective* is strongly supported. This is because there is not an attempt to describe things as they are, nor it is discussed whether or not things can be described "as they are". Instead there is a attempt to characterise how things appear to people. After all "human beings do not simply perceive and experience, they perceive and experience *things*" (Marton, 1986, p. 33, emphasis in the original).

Within the constructivist paradigm for educational research, the act of inquiry begins with issues and/or concerns of participants and unfolds through a "dialectic" of iteration of analysis, critique, and then reiteration, reanalysis and further critique, until it eventually leads to a joint construction of a case (i.e. outcome or findings), among inquirer and respondents. These "joint constructions" coming out of the activity of the inquiry, can be evaluated in terms of "fit" with the data and relevant information, but also to the extent they "work", have "relevance" or are "modifiable", providing a credible level of understanding (Guba & Lincoln, 1989).

The present inquiry places itself within the *verstehen* tradition and within the constructivist paradigm for educational research. Learners' conceptions about various phenomena and the ways in which they construe reality are considered seriously, whereas the interpretative analyses of these conceptions are constructed within a *second-order* perspective (cf. Marton, 1981a). An emphasis is put on learners' idiosyncratic constructions and the ways these constitute systems of explanation and/or topographies of knowledge and experience. These constructions are

considered to be under constant restructuring and testing in the light of more plausible or fruitful ideas and explanations. In this respect, it could be claimed that there is a *phenomenographic* approach in the elicitation and interpretation of learners' conceptions and conceptual change.

3.2. Research methods chosen for this inquiry

Researchers have used a variety of methods and techniques to investigate children's ideas or alternative conceptions in science (see for example, Osborne & Freyberg, 1985; White 1988; White & Gunstone, 1992). *Word association* (Shavelson, 1974) *Prediction-observation-explanation* (Champagne, Klopfer & Anderson, 1980) *concept maps* (Novak & Gowin, 1984), *interviews about instances and events* (Osborne & Gilbert, 1980a, Watts, 1983a) and *drawings* (Nussbaum & Novick, 1982) are some of these research methods or techniques. In the present inquiry interview methods have mostly been used and this is the focus of the analysis below.

Many researchers in the field of science education have turned to the interview as a research tool because it has proved to be a remarkably powerful way of getting to know how children describe and explain the world around them. What we learn from a carefully conducted interview is how children are "thinking about the world differently" (Osborne & Freyberg, 1985, p. 5). More importantly, interviewers try to get children's conceptions into their heads, not their conceptions into the heads of children (Osborne & Freyberg, 1985). In conducting an interview, the image of a learner changes, then, from one where the learner has the science in her head, has bits of it, or has nothing, to the image of heads full of knowledge about the world and its phenomena. This is not necessarily seen as a deficiency, or "lack of understanding", rather this knowing about the world is seen as a key to effective learning of science (Hills, 1989).

The interview method, pioneered by Piaget in the early 1920's, was developed to investigate the nature and extent of the knowledge of children about the world (Piaget, 1929; 1969; 1970). Piaget used drawings, actual objects and events to probe young children's constructions of meanings for science concepts and natural phenomena. He modified the method, in the 1940's, to include tasks with objects as well as dialogue. Current techniques employ modifications of the classic *clinical interview* (Piaget, 1929) to explore children's views of science concepts and their explanation of events (Osborne & Freyberg, 1985; Hashwesh, 1988).

In many studies in the field of science education research, interviews usually have the form of one-to-one conversation, or sometimes group discussions. The style of these interviews is usually *informant* in the sense that it intends to "gain some insight into the perceptions of a particular person (or persons) within a situation" (Powney & Watts, 1987). The structure of the interviews can range from tightly structured, where the sequence of questions is well defined, to semi-structured or loosely structured, where the order of questions is not so important and the interview develops within the flow of discussion. For example, Watts (1983b) investigates children's alternative frameworks on force using a semi-structured interview technique (Interview-About-Instances, cf. next section), whereas Nussbaum and Novak (1976) utilise more structured interviews to explore children's ideas about the concept of the earth. It should be noted that in such studies the interviewer must be careful in organising a convenient environment for the conduct of the interview, allowing as much freedom of expression as possible for the interviewee.

The interview has some problematic characteristics, as all research methods do. It has often been claimed that because children see adult interviewers as teachers and/or authorities it is a difficult task to induce child conversation (Osborne & Freyberg, 1985). Moreover, Lythcott & Duschl (1990) refer to three main difficulties in the process of interviewing. The first is that interviewing involves skills that take a long time to develop. The second difficulty deals with the danger of misinterpreting the

interviewee's responses. This is important in the use of clinical interviews because the research seeks to claim that if the learner said *A* then *A* is what the learner knows. Both the interviewer's and the learner's utterances should be separable. Nevertheless, it has often been claimed that it is very difficult, or rather tempting, for the interviewer to avoid suggesting an appropriate response to the interviewee and then claim that this response is what the interviewee actually believes (Posner & Gertzog, 1982; Piaget, 1929). The third difficulty refers to a possible hypothesis-oriented narrowness of the interviewing process. This can happen in the attempt of the interviewer to hold some hypothesis about what the learner knows, which may guide the general flow of the conversation, with a danger of missing whatever emerges outside the predictions of that hypothesis.

The main criticisms in the use of the interview method are related to the evaluation of the research outcomes. The central issue of the interview method is its dependence on the subject's verbal responses, which are often criticised as an invalid and unreliable source of information (Sutton, 1980). It is noted, however, that *validity* and *reliability* are psychometric issues which become important "when the specific purpose of measurement has been determined-when the constructs to be measured are theoretically specified" (Swanson, Schwartz, et al., 1981). In this respect, *validity* refers to the extent to which a measuring instrument measures what it purports to measure, whereas *reliability* refers to extent to which research findings can be replicated. Hence, it is difficult to imagine how these two terms can be used as a criterion for the evaluation of interview outcomes, when the purpose of the interview is to elicit multiple conceptions and not to measure certain psychological constructs or extend a theory to a new level. Watts (1983a) goes further by claiming that concepts like validity and reliability belong to other research paradigms and "in many senses are incommensurable when used in a different research movement". However, he argues that attention should be placed in the "authentication" of the research outcome.

3.3. The Interview-About-Instances technique

The elicitation of characteristic features, alternative interpretations or conceptions of children's science, calls for a method which has to be responsive to the learners involved and which recognises their individuality and idiosyncrasy, while at the same time it allows a systematic attempt to explore this individuality. As Driver & Easley (1978) have long suggested:

> In learning about the physical world, alternative interpretations seem to be the product of pupils' imaginative efforts to explain events and abstract communalities they see between them (p. 62).

The Interview-About-Instances (I.A.I.) technique appears to reveal representations, or investigate topographies of children's conceptions in a non-threatening, friendly way, within a framework of open discussion between participants. It consists of tape recorded dyadic discussions between a researcher and a learner using a deck of cards and mainly focusing on applications of a single word (Osborne & Gilbert, 1979a; 1979b; 1980a; 1980b; Gilbert, Watts & Osborne, 1985). The cards consist of a series of line drawings which depict various situations, where a specific concept in science may (or may not) be seen to be involved. The pictures are usually designed around a single concept (as a physicist would perceive it). The deck of cards usually contains a variety of clear cut examples, some non-examples and sometimes a number of 'borderline cases' which can be described as unusual or unorthodox applications of the concept under investigation.

The interviewees are asked to decide whether the instances depicted on the cards are examples or non-examples of a certain concept according to their understanding of it and to give reasons why they think so. These reasons are probed using, as far as possible, the learners' language for the description of the instances. In some of the depicted instances, a 'dynamic element' is present, which requires some sort of prediction from the learner for the outcome of a certain situation.

The interviews are semi-structured and an informal discussion is allowed to develop concerning various meanings or conceptions of a certain concept or phenomenon. The recordings of the interviews are fully transcribed and a scheme for analysis is developed dependent upon the specific purposes of an inquiry. The I.A.I. approach has been used to explore a range of topics, e.g. *force, energy, heat* and *light* (Watts 1983a) or *light* and *colour*, *force* and *movement* (Zylbersztajn, 1983).

Some of the advantages of the technique are that it can be applicable over a wide age range, it appears to be enjoyable for both the interviewer and the interviewee and it is concerned with the learner's view rather than merely examining if the learner has the correct scientific view. Moreover, it seems to have advantages over written answers in terms of flexibility and depth of the investigation. On the other hand, some limitations may arise from the problem of choosing a small but adequate set of instances, or from the claim that the order of instances may influence learners' responses. Furthermore, the conduct of interviews, the transcribing, the analysis of transcripts and the reporting of the analysis appear to be time consuming processes (Osborne & Gilbert 1980b).

Bearing in mind the context of the interview-about-instances technique "examples" of the word are usually defined as instances of the concept and "non-examples" are usually defined as non-instances of the concept. Within the context of the present inquiry, the interview-about-instances technique has been modified in a way that the cards depicted only instances where frictional phenomena were present (Pre-Intervention interviews), or instances of the concept of friction (Post-Intervention interviews) (cf. § 3.4). This is because the main aim of this inquiry has been to investigate children's alternative conceptions about friction and frictional phenomena and highlight some aspects of their change from naive or intuitive to more elaborated and advanced. In this respect the interview cards have been used as instances or springboards for discussion about frictional phenomena and friction. Summers et al. (1993) have used the interview cards in a similar way in order to investigate teachers'

alternative conceptions about force, friction, energy etc., and how these change over time. Thus, it was not intended to use the interview cards in order to investigate the meaning and conceptualisation of a certain word-concept in terms of children's classifications of the cards as instances and non-instances of that word-concept. Instead, they were used to elicit relevant pieces of knowledge, explanatory statements and propositions within the context of the depicted instances.

3.4. The generation of the interview cards

The generation of the I.A.I. cards is a step by step process. It has been suggested that a certain algorithm can be followed. Although there have been some adaptations within the context of this inquiry, the algorithm presented by Watts (1981) and by Gilbert, Watts & Osborne (1985) has been adopted and followed. The phases of the suggested algorithm are the following:

a. Identify scientists' meaning of the word (under investigation)
b. Analyse the scientists' science view (about the word-concept)
c. Identify 'criterial attributes' of the word in scientists' science
d. Identify 'non-criterial attributes' of the word in scientists' science
e. Identify sources of possible linguistic confusion
f. Identify sources of invalid use of the scientists' science meaning
g. Review other work in 'children's conceptions' (about the word-concept under investigation)
h. Producing cards (design of the depicted instances)
j. Ordering cards into a deck. (Watts, 1981, pp. 4-8; Gilbert, Watts & Osborne, 1985 pp. 13-16)

Most of the phases of this algorithm, (**a-f**) and (**h-j**), in reference to the words-concepts of "force" and "friction", are considered in the following parts of this section. A review about children's conceptions on friction is presented in Chapter 2 (cf. § 2.6).

It needs to be pointed out though, that the reason why the word-concept of "force" is also under consideration here, is because the elicitation of children's ideas about

frictional phenomena or frictional effects, in the interviews conducted before the teaching intervention, was seen through some of their conceptions of "force" (cf. § 3.5). Thus, although the word "force" was used in the "focus questions" (meaning the questions that were printed on the cards below the drawing of an instance), the discussion that followed focused on an implicit elicitation of children's explanations of frictional phenomena, without necessarily naming them as such. This was achieved with some "key questions" that were prepared in advance and they aimed to probe and investigate such conceptions and/or explanations (cf. § 3.5).

All of this process was designed in order to avoid asking children explicitly about their conceptions of "friction" by actually using the word *friction*, before the teaching intervention. A rationale for this can be expressed with a couple of arguments listed below.

"Friction" does not seem to be such a common word in the everyday vocabulary of 10-11 year-old children, or at least not as common as "work", "energy" or "force". This assumption was corroborated by the fact that in the pre-intervention interviews, only one child referred to the term of "friction" (cf. § 4.1), and during most of the time of the teaching intervention the children were using words like "gripping", "catching", "holding" or "slipping" to refer to frictional phenomena under investigation[1]. Nearly at the end of the last teaching session the term was introduced and put into the context of their investigations (cf. § 4.2 and § 5.2).

On the one hand the research could try to investigate children's conceptions about a word that they do not frequently use and perhaps they have a rather poor context of meanings and/or conceptions. On the other hand it could choose an implicit way to investigate conceptions of frictional phenomena, through children's explanations about them and within a context of conceptions about "force". It seems more appropriate to do it in this second way, within a context of a rather holistic approach

[1] All these for the English language of course, because things can be quite different in Greek (cf. § 2.1). Nevertheless, the same policy was also followed for the study in Greece.

that includes an investigation of children's conceptions before and after a teaching intervention, with a focus on anticipated conceptual change. Some points of critique on these arguments are considered in the last chapter.

A presentation of the phases of the algorithm for the generation of the interview cards within the context of this inquiry follows.

3.4.1. Identify scientists' meaning of the words *force* and *friction*

If some science text books are reviewed, a number of views about *force* can be found like the following ones:

- A force is a push or a pull.
- Forces act in pairs.
- A force can make things change shape.
- Force is something that can change the state of motion of an object, as when a golf club hits a stationary ball. Forces can also maintain the position of an object, as when somebody holds a ladder steady against a wall.
- The total force on a body moving at constant velocity is zero (0).
- Forces are interactions of nature. There are four fundamental forces which control the behaviour of everything in the Universe (gravitational, electromagnetic, strong and weak).

A similar approach for the word *friction* produces meanings as follows:

- Friction is a force which opposes the movement of an object.
- Friction may cause heat, as when a meteorite enters the atmosphere. The heat that is generated by friction is almost always enough to burn it before it reaches the ground.
- Friction can be present between surfaces even if they are not in relative motion.
- Rolling friction is a lot smaller than sliding or static friction.

3.4.2. Analyse the scientists' science view

This kind of analysis is in terms of the vagueness and ambiguity of the words *force* and *friction*. According to Quine (1960):

> Vagueness is a natural consequence of the basic mechanism of learning. The penumbral objects of a vague term are the objects whose similarity to ones for which the verbal response has been rewarded is relatively slight. Or, the learning process being an implicit induction on the subject's part regarding society's usage, the penumbral cases are the cases for which that induction is most inconclusive for want of evidence. The evidence is not there to be gathered, society's members having themselves had to accept similarly fuzzy edges when they were learning. (p. 125)

The distance between the denotative meaning and the connotative meaning of a word constitutes its range of vagueness. For the word *force* the range of vagueness is low (Gilbert, Watts & Osborne, 1985, p. 13). Force can be mainly viewed within the four basic interactions of nature (gravitational, electromagnetic, strong and weak). *Friction* is a force and can be mainly attributed to electromagnetic interactions at molecular or atomic level.

The ambiguity of a word is different from its vagueness. As Quine (1960) puts it:

> Vague terms are only dubiously applicable to marginal objects, but an ambiguous term such as 'light' may be at once clearly true of various objects (such as dark feathers) and clearly false of them. Sometimes the ambiguity of a word is resolved by the rest of the sentence that contains it; thus 'light' when followed by 'as feather'. But sometimes the ambiguity of a word infects the containing sentence; thus 'bore' in *'Our mothers bore us'. Then either it is resolved by broader circumstances of* utterance, e.g. some contiguous remark on birth or boredom, or else communication fails and a paraphrase is in order." (p. 129).

Thus, multiple but equally legitimate meanings of a word constitute its ambiguity. In physics the ambiguity of *force* is very low (Gilbert, Watts & Osborne, 1985 p. 14), but within a societal context of the usage of the word some ambiguity exists especially when the word is used as a verb. For example, we say "she was forced to do that, although she didn't want to", "force a person's hand to do something" etc.

In physics the ambiguity of the word *friction* seems to be very low. Friction, as a phenomenon, is difficult to be described and analysed, but if we deduce its primary conception to one of the four basic interactions of nature, the electromagnetic, some common agreement amongst scientists has instantly been achieved.[2] The societal context of the usage of the word *friction* may enclose some degree of ambiguity, especially when it is used in a metaphorical sense. Thus, we may say "there's a lot of friction amongst political parties these days" or "noise is the main source of friction in the relationships of neighbours". In these cases, *friction* has a meaning of a difference of opinion, often leading to an argument and quarrelling. It could be claimed, in a rather conjectural way though, that the word *friction* is not often used, or at least it is

[2] For more information on these issues see the respective analysis in Chapter 2. Some brief comments are only presented here .

not used as frequently as the word *force* within the daily vocabulary of 10-11 year old learners.

3.4.3. Identify 'criterial attributes' of the words *force* and *friction* in scientists' science

Criterial attributes are some essential qualities, which should constitute some basic characteristics of a word/concept, identified and recognised by scientists, in order to use a certain word/concept in a generally acceptable way. The criterial attributes for *force* have been specified elsewhere (Gilbert, Watts & Osborne, 1985) and they are the following:

- its magnitude and direction,
- the body on which it acts,
- the body that exerts the force,
- the nature of the force, for example, the type of interaction occurring, and
- the effects of the force, for example, changes of direction, size, shape. (p. 14)

The criterial attributes for *friction* are mainly the same, since friction *is* a force.

3.4.4. Identify 'non-criterial attributes' of the words *force* and *friction* in scientists' science

Some statements about certain situations or circumstances, which involve or demonstrate a particular aspect of a word/concept, can be considered as non-criterial attributes of that word/concept (Gilbert, Watts & Osborne, 1985). For *force* some of these statements are taken from NCC (1992) and some from Warren (1979). Bearing in mind the context of the interview cards used in this inquiry, they could be the following:

- Forces can be measured in Newtons.
- Weight is a measure of the force of gravity on an object (NCC, p. 33).
- Objects fall to Earth because of the force of attraction between the object and the Earth (NCC, p. 26).
- Unless there is a resultant external force acting upon it, any body moves in a constant speed in a straight line [Newton's 1st law of Motion] (Warren, 1979, p. 7).
- The greater the mass, the greater the force needed to change an object's movement at a certain time (NCC, p. 26).
- Forces result from the interactions of bodies. The force exerted by body A upon body B is equal in magnitude, opposite in direction and in the same straight line

as the force exerted by B upon A [Newton's 3rd Law of Motion] (Warren, 1979, p. 10).

- A turning force (torque) has more effect further away from the pivot (NCC, p. 65).

For *friction* some similar statements could be the following:

- Friction is proportional to the normal force and independent of the area of contact.
- Friction is important and necessary for the movement of wheels or the movement of people.
- Factors that minimise and/or eliminate friction are: the use of wheels or rollers, lubrication etc.
- A "surface roughness theory" of friction could be a good approximation for the explanation of some frictional phenomena, like sliding wood over wood.

3.4.5. Identify sources of possible linguistic confusion

The sources of linguistic confusion can be grouped into three types: antonyms synonyms and homonyms (Gilbert, Watts & Osborne, 1985, p. 15). For *force* some linguistic characteristics can be as follows:

- *Antonyms:* weakness, incapacity, inability, inadequacy, tameness, deficiency etc.
- *Synonyms:* strength, dynamism, enforcement, potential, impetus, intensity, power, ability, effect, drive etc.
- *Homonyms: fours* (quadruples), *fauces* (a cavity of the mouth), *faucet* (tap) (op. cit.), *farces* (coarsely comic dramatic work based on ludicrously improbable events).

For *friction* some linguistic characteristics can be as follows:

- *Antonyms:* slippage, skidding, smoothness, regularity, conformity, uniformity, harmony etc.
- *Synonyms:* rubbing, gripping, sticking, wearing away, rasping, resistance, abrasion, attrition, chafing, conflict, disagreement, irritation etc.
- *Homonyms: fiction* (kind of literature describing imaginary events and people), *fraction* (a numerical quantity that is not a whole number; a very small piece or amount).

For the words 'δύναμη' [force] and 'τριβή' [friction] which were used in the interview cards for the study in Greece, things are a bit different, but since such linguistic issues are not the main focus for the present inquiry, a relevant analysis will not be

presented. Nevertheless, some other linguistic issues concerning conceptual understanding and development will be taken into account in the following chapters (cf. § 2.1.).

3.4.6. Identify sources of invalid use of the scientists' science meaning for *force* and *friction*

Common use of certain meanings of these words are probably the major source of invalid use of scientists' science meaning for them (Gilbert, Watts & Osborne, 1985, p. 15). There can be several such examples for *force* like the following: "forced labour", "forced landing", "force the issue", "the force of the argument", "forced march" etc. Some respective examples for the word *friction* may be found within the context of its metaphorical meanings such as the following: "there's often friction between parents and children", "political friction between two countries" etc.

A second source of invalid use of the scientist's science meanings can be the misuse of such words within various contexts of scientific discourse (op. cit.). This kind of misuse of words often causes confusion for scientists and learners. A collection of misuse of *force* , mainly derived from text books has been identified by Warren (1979). Such examples of misuse can be the following:

- The supposition of force where none exists, to account for effects noted in a situation (Gilbert, Watts & Osborne, 1985, p. 15).
- The omission or misuse of vector components, as in the case of the system of forces supposed to produce equilibrium when friction acts in the surfaces between a block and a bench (p. 11).
- An inadequate description of the bodies exerting the forces in the situations where the interactions are taking place, as for example a body resting on a table (p. 58).

Some respective example-statements for *friction* are also found in Warren (1979) such as the following:

- "One very common use of the term "reaction" occurs in the discussion of friction" (p.12).
- "Confusion between pairs of forces acting on different bodies (according to the third law) and pairs of forces acting on a single body that is in equilibrium (according to the first law) is sometimes explicitly taught. Thus when one pushes a table the force of friction exerted by the ground on the table preventing acceleration is wrongly called the reaction to the force exerted by the hand" (p. 12).

- "Although it is a very common phenomenon, rolling friction is rarely mentioned other than in specialist advanced courses, and much confusion arises from attempts to interpret frictional resistance to vehicles or bodies rolling down slopes in terms of sliding friction" (p. 30).

3.4.7. Producing the cards

Choosing the instances which are going to be depicted on the interview cards is the most difficult task of the whole process. Several issues need to be taken into account such as the overall aims of the inquiry, the purposes of using the interview cards within that context and finally the choice and the design of appropriate instances.

The design of the interview cards is "a mixture of art and science" (Watts, 1983a, p. 2.24; Gilbert, Watts & Osborne, 1985, p. 16)[3]. The same style, format and outline that has already been used in earlier studies (Osborne & Gilbert, 1979a; Stead & Osborne, 1980; Watts, 1983b; Osborne & Freyberg, 1985) are also adopted and used here.

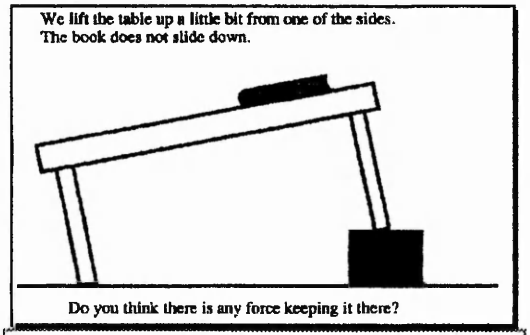


Fig. 3.1: A reduced interview card used as an example to illustrate the format and the outline of the cards described below (cf. Appendix II)

Thus, line drawings of various objects and the "stick people" are mainly depicted on the cards. All of the depicted instances are two-dimensional drawings, although some shading is used to introduce a sense of background, perspective or motion. Nevertheless, it has been attempted to keep the drawings as simple, plain and clear as possible in order to convey specific ideas in a more effective way (Swift, Watts & Pope, 1983, p. 14).

[3] For the present inquiry the interview cards were designed with the aid of a Macintosh computer. The software that was mainly used for the design of the cards was MacDraw II.

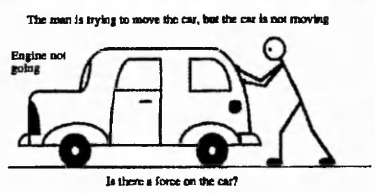
There is a brief description of the instance on top of each card, then the drawing follows and just below, a *focus question* is printed, which is used as a springboard to initiate discussion. The cards have roughly the size an A_5 page. Some of the cards include *'dynamic elements'* which can be used as further probing instances within the original ones. For example, the instance depicted in fig. 3.1 includes some 'dynamic elements' which can be further probed by using some hypothetical "what would happen if ... ?" questions such as the following:

- What would happen if we lifted the table a bit higher from one of the sides? or,
- What would happen if the book was bigger? or,
- What would happen if the surface of the book or the table was smoother or rougher?

The research assumes that the learners' "predictions and explicit explanations endorse their tacit understandings and constructions of the situations" (Watts, 1981, p. 6).

The ideas for the design of the cards are taken from other relevant studies in the field and from every-day-life occurrences which are considered to be of interest for young children.[4]

Most of the instances depicted on the interview cards have been used in other research projects and some are related instances to those original ones. A board, presenting a reduced version of the "Pre-Intervention Interview Cards" with relevant comments on their origin and other related issues, follows below:

Pre-Intervention Interview Cards	*Origin and Comments*
	• This card has been used for the elicitation of children's ideas on the concept of force in Osborne (1980) and in Osborne & Gilbert (1979) primarily for the investigation of the concept of work. • It has also been used for the elicitation of teacher's ideas on the concept of force in Summers, Kruger & Palacio, (1993).

[4] For a complete presentation of the Interview cards in the format that they were shown to the children in both studies, see **Appendix II**.

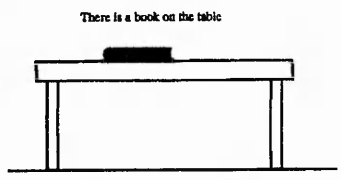
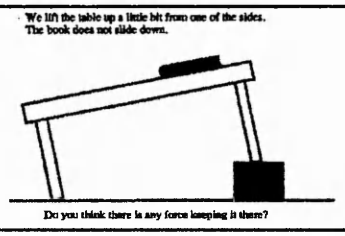
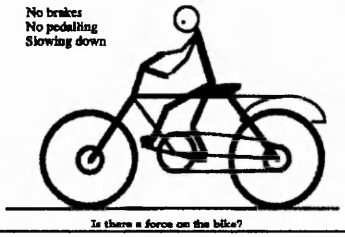
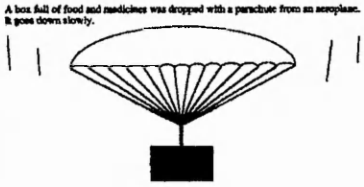
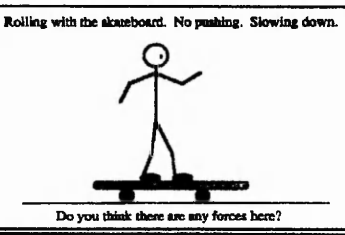
	• This card has been used for the elicitation of children's alternative frameworks about force in Watts (1983a). • As an instance, it has been extensively considered and analysed in Minstrell (1982). • It has also been used for the elicitation of teacher's ideas on the concept of force in Summers, Kruger & Palacio, (1993) and in Kruger, Palacio & Summers, (1991). • This is the only instance in the Pre-Intervention Interview Cards where the frictional force is not present, in any form.
	• As far as I know, this instance has not been used before, although similar depicted instances with objects that were put on tilted surfaces (e.g. a rubber and an ink bottle on the surface of a tilted book) have been used elsewhere (Summers, Kruger & Palacio, 1993, p. 16). • This instance has been used both in the Pre-Intervention Interviews and in the Post-Intervention Interviews, after changing the focus question for the latter.
	• This card has been used for the elicitation of children's ideas about force in Osborne (1980); Osborne & Freyberg (1985). • It has also been used for the elicitation of teacher's ideas on the concept of force in Summers, Kruger & Palacio, (1993). • This instance has been used both in the Pre-Intervention Interviews and in the Post-Intervention Interviews, after changing the focus question for the latter.
	• According to my information, this card has not been used before, although the sky diver instance has been used in Stead & Osborne (1980) in order to explore friction/air resistance. The parachutist has been used as a pictorial task in Twigger et al. (1994) to investigate children's ideas about force and motion. It has also been used as a computer simulation scenario in Hennessy et al. (1995) to investigate similar issues. • The sky diver has also been used for the elicitation of teacher's ideas about friction/air resistance in Summers, Kruger & Palacio, (1993). Forces acting on a free fall parachutist is also an example of what 'pupils could do' in AT4 of the National Curriculum (DES, 1991, p. 30) • The parachute is a common instance that appears in various textbooks (Jennings, 1993, p. 84).
	• This instance with a skateboard rider, has not been used before, although it is closely related to the bicycle and the rider. • Many children have skateboards and/or have seen other children playing with them in streets and squares, thus it seemed to be a rather common and interesting instance to present and discuss.

Table 3.2: The Pre-Intervention Interview Cards with respective comments on their origin and previous use

During the development of this inquiry, in the study in Greece, it was estimated that a couple more cards could be included in the Pre-Intervention Interviews in order to investigate further some of children's conceptions about frictional phenomena (see Table 3.3). Hence, it was considered that an instance of dragging a body along a surface would be challenging in eliciting children's explanatory conceptions of such a

phenomenon. An instance with a person dragging a chair along the surface of the floor was used for that purpose. Furthermore, an instance that would seek to investigate further children's explanatory conceptions about a notion of a "drag force" (cf. Appendix I) or air-friction was considered to be of interest (cf. the instance with the parachute). An instance with two children playing with a tennis ball was used for that purpose.

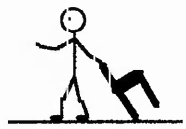
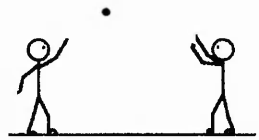
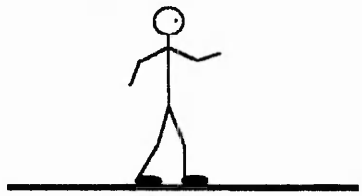
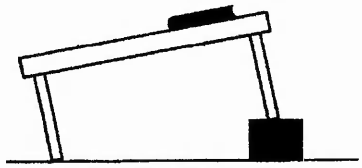
Pre-Intervention Interview Cards	*Origin and Comments*
Dragging a chair.  **Do you think there are any forces here?**	• As far as I know, this card has not been used before as such, although one of the cards that Watts (1983a) used a similar instance that depicted two persons trying to drag a huge stone. • It depicts an everyday activity and many of the children claimed to have personal experience of such an instance.
Throwing a tennis ball to the child over the other side.  **Do you think there are any forces here?**	• According to my information, this card has not been used before as such, although it is similar to the one with a golfer that hits a golf ball and it starts moving through the air (see Watts, 1983a). • Since golf is not a very popular sport in Greece, I thought I could use a more familiar instance with children playing with a tennis ball.

Table 3.3: Two additional Pre-Intervention Interview Cards that were used in the study in Greece with respective comments on their origin and previous use

A similar presentation for the Post-Intervention Interview Cards can be as follows:

Post-Intervention Interview Cards	*Origin and Comments*
Walking along the road. Is there any friction here? 	• This instance has not been used before as such, although in Stead & Osborne (1980) and (1981) a person was depicted in a card walking and slipping because of a banana skin which was left on the pavement. • The idea was taken form McClelland (1983) where he describes how a person manages to walk. • Walking is a natural every-day process but we rarely think about the role of friction in this process. Thus, it was considered as an interesting instance for discussion.
We lift the table up a little bit from one of the sides. The book does not slide down.  **Do you think friction is keeping it there?**	• According to my information, this instance has not been used before, although similar depicted instances with objects that were put on tilted surfaces (e.g. a rubber and an ink bottle on the surface of a tilted book) have been used elsewhere (Summers, Kruger & Palacio, 1993, p. 16) aiming, mainly, to investigate teachers' conceptions of friction. • This instance has been used both in the Pre-Intervention Interviews and in the Post-Intervention Interviews. • In the Post-Intervention Interviews the focus question of this card has been changed, since the word 'friction' is used explicitly within the context of the interview discussion.

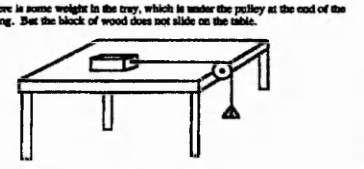
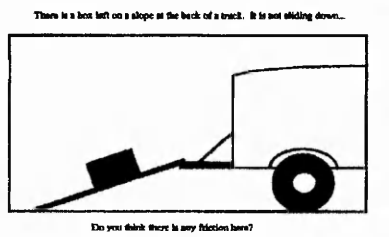
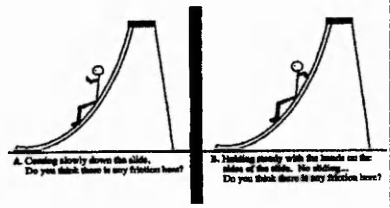
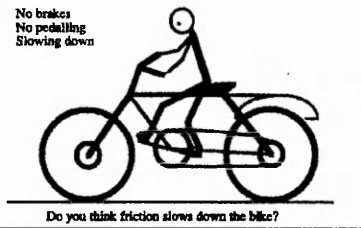
	• This instance was inspired from the experiments that took place during the teaching interventions. It links directly to experiments that were conducted by Leonardo and Amontons or even by Coulomb (cf. Chapter § 2.2). • A similar instance has been used as a task in Champagne & Klopfer (1984) in an attempt to investigate children's naive theories (p. 185). • Since this kind of experimentation was one of the basic means for the exploration of the nature of friction, it seems like a natural consequence to have a discussion about it, within the context of the Post-Intervention Interviews.
	• Similar instances with boxes on slopes have been used in Osborne (1980); Osborne, Schollum & Hill (1981) and Gilbert, Watts & Osborne (1985). • Boxes on slopes, have also been used, as instances, for the elicitation of teacher's ideas on the concept of frictional force in Summers, Kruger & Palacio, (1993) and in Kruger, Palacio & Summers, (1991). • The truck and the sloping board are part of the instance here, adding some sense of familiar context for this card.
	• This is a double card, since two instances are depicted on it. These instances have been used in Stead & Osborne (1980) and (1981), during their interview study about children's ideas on friction and in a questionnaire aiming to explore children's views on friction and movement. • Games with the slide are rather frequent and common among children and they have personal experiences of relevant instances.
	• This card has been used for the elicitation of children's ideas about force in Osborne (1980); Osborne & Freyberg (1985). • It has also been used for the elicitation of teacher's ideas on the concept of force in Summers, Kruger & Palacio, (1993). • This instance has been used both in the Pre-Intervention Interviews and in the Post-Intervention Interviews. • In the Post-Intervention Interviews the focus question of this card has been changed, since the word 'friction' is used explicitly within the context of the interview discussion.

Table 3.4: The Post-Intervention Interview Cards with respective comments on their origin and previous use

A respective presentation of the Interview Cards from the 'physicist's point of view' (vector analysis), in reference to the depicted instances, accompanied by some comments, can be found in Appendix III. Similar analyses have been presented in Osborne, Schollum & Hill (1981, p.38-40) and in Gilbert, Watts & Osborne (1985, p. 23).

3.4.2. Ordering the cards into two decks

The cards that were used in the pre-intervention interviews in England were presented to the interviewees randomly and this didn't seem to affect their responses. In the post-intervention interviews the cards were ordered in a sequence that is presented in

Appendix II (pp. 05 -10). Similarly the interview cards that were used in the study in Greece are presented in the order that they were discussed with the interviewees in Appendix II (pp. 11-17). A couple of pilot interviews, that were initially conducted in each country respectively, helped to put the cards in a certain order.

3.5 The interview settings in England and in Greece.

In England the interviews were conducted at a small foyer, which was quiet and very rarely people passed by.

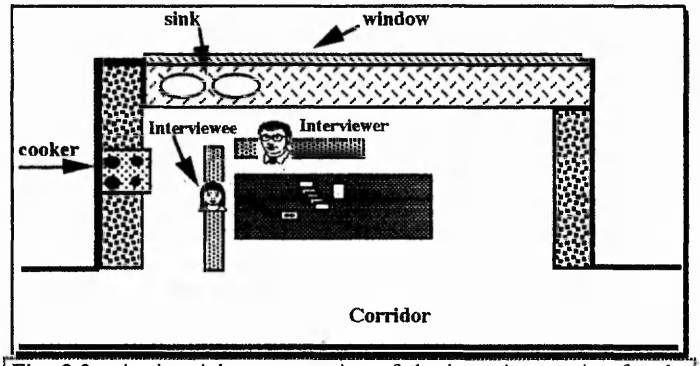


Fig. 3.2: A pictorial representation of the interview setting for the study in England.

During the interview process, the interview cards and a notebook were placed on the table, in front of the interviewer. A small tape recorder was also placed on the table and a sensitive, mini microphone was stuck on a piece of plasticine in front of the interviewee (see fig 3.2).

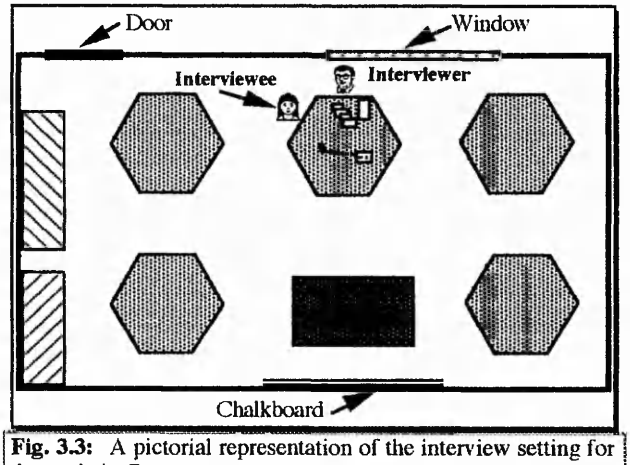


Fig. 3.3: A pictorial representation of the interview setting for the study in Greece.

In Greece the interviews were conducted in one of the classrooms which was mainly used as a science laboratory for the two upper classes of the primary school.

In both studies, the interview setting was within familiar school areas, hoping that the children would perceive them to be a convenient, non-threatening environment.

3.6. The conduct of the interviews

Within the context of the present inquiry and in both studies (England & Greece), the interviews were conducted in two phases, using two decks of cards. Some interviews were conducted before the teaching intervention and are called **Pre-Intervention Interviews** and some were conducted after the teaching intervention and are called **Post-Intervention Interviews** (see fig. 3.4).



Fig. 3.4: A pictorial representation of the sequence in the conduct of the interviews.

In both studies the researcher approached the teachers of the classes (Year 6 and E' Grade respectively) and explained to them what he wanted to do and the extent of the involvement of the teachers and the children. Both of the teachers agreed to collaborate, but they also suggested that permission was needed from the head-teacher of each school. Hence, in each case, the researcher and the teacher arranged a meeting with the head-teacher of the school, where the purposes of the inquiry were discussed together with the extent of involvement of the participants. The researcher promised to be discreet in the conduct of the research and also to handle the obtained data with anonymity. In this respect, both of the head-teachers gave permission for the conduct of the inquiry in their schools.

All of the interviews were conducted in the native language of the children involved in the two studies, in English and in Greek respectively. In both cases the children were asked if they wanted to be interviewed with the presence of a tape recorder and the answer was affirmative, with no exceptions. The interviewer always explained in advance that he is very interested to hear what they have to say about the instances

depicted on the cards and that it would be easier for him to use the tape recorder, so he can concentrate in the conversation instead of keeping notes, which would take more time and distract the attention of both, the interviewer and the interviewee. The children were told that the interviews are confidential, but they could always listen to what they have said, if they wanted to do so. Some children asked to listen to themselves after the end of an interview and that happened, whereas most of the children did not appear to pay any attention to the tape recorder and concentrated on the discussion, which they seemed to enjoy, as they mentioned. It was pointed out repeatedly that there were no "right" or "wrong" answers in what they were going to say in the interviews and they were encouraged to express their views freely.

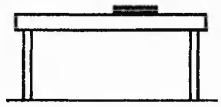
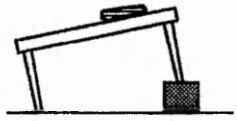
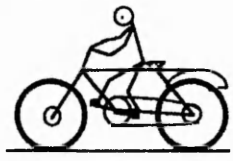
The interviewer had visited both of the schools many times and there was a friendly relationship with the children, since he had spent some time talking to them during the breaks or whenever it was possible. Especially the English children were very curious to learn things about Greece and Greek people and there was always a topic for discussion.

Each of the pre-intervention and the post-intervention interviews lasted approximately fifteen to twenty minutes. In England nine (**9**) children were interviewed twice, once before and once after the teaching intervention, whereas in Greece the respective number of interviewed children was ten (**10**).

During the course of an interview the children are asked some questions in order to elicit their conceptions. Some of these questions can be called *view-finders* (Bell, 1995, p. 355) and they aim to encourage children to talk or explain further a certain issue. Hence, questions like "*can you tell me more about that?*", "*can you think of another example?*" or expressions like "*I don't quite understand. Could you explain that to me again?*", "*That's an interesting idea. Can you explain that a bit?*", are all *view finders* in a way that they probe further children's thinking.

In this inquiry, apart from these questions and expressions, some other kinds of questions were also used in the conduct of the interviews. Thus, in the pre-intervention interviews some '*key questions*' were used in order to probe children's understanding and explanations on certain aspects of the depicted instances, where friction and/or frictional phenomena are present (cf. relevant analysis in Appendix III). Moreover, each card was anticipated to elicit certain aspects of children's conceptions and explanations about the depicted instances.

Some of the purposes for using each card within the context of this inquiry are presented below (Table, 3.5), together with some *key-questions* which aimed to probe children's understating and conceptions during the conduct of the pre-intervention interviews.

Interview Cards	*Focus questions and relative "Key questions"*
	*Is there a force on the car?* • Do you think there are any forces at the touching points of the wheels (or tyres) and the ground? • Why do you think the car is not moving? *This card aims to elicit children's understanding and explanations about the motionless condition of the car*
	*Do you think there are any forces here?* • Do you think there is any force from the table towards the book? • Do you think there are any forces from the floor towards the legs of the table? *This is card was used as an introductory card to the following one. It is the only card that frictional phenomena are not present. Nevertheless, the card aims to elicit some of children's conception of weight & gravity or a possible notion of a reaction force.*
	*Do you think there is any force keeping it (the book) there?* • Do you think there are any forces at the touching points of the book and the surface of the table? • Why doesn't the book slide down the table? • What will happen if we lift the table a bit higher? *This card aims to elicit children's ideas and explanations about the motionless condition of the book on the tilted table.*
	*Is there a force on the bike?* • Do you think there are any forces at the touching points of the wheels (or tyres) of the bike and the ground? • Why does the bike slow down and eventually stop? *This card aims to elicit children's ideas and explanations about the slow-down of the bicycle and the reasons why it happens*

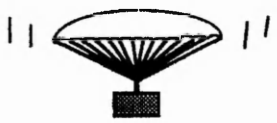
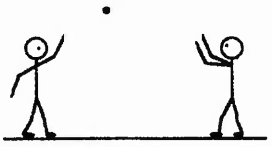
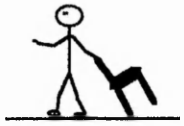
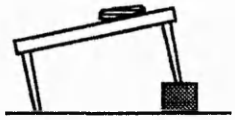
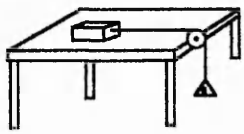
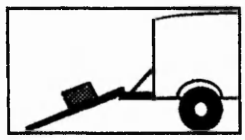
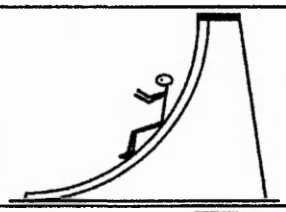
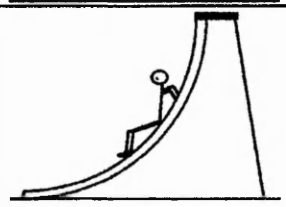
	*Do you think there are any forces here?* • Why does the parachute go down slowly? • Do you think that wind is a force here? *This card aims to elicit children's ideas and explanations about the slow descent of the parachute in the air and how this affects its motion*
	*Do you think there are any forces here?* • Do you think there are any forces at the touching points of the wheels (or tyres) of the skateboard and the ground? • Why does the skateboard slow down and eventually stop? *This card aims to elicit children's ideas and explanations about the slow-down of the skateboard and the reasons why it happens*
	*Do you think there are any forces here?* • Do you think that there are any forces exerted at the ball when it is in the air? • Do you think that the ball has weight when it is in the air? *This card aims to elicit children's ideas and explanations about the forces acting on the ball while it is in the air, or about its weight and to identify any possible ideas about air-friction (or resistance).*
	*Do you think there are any forces here?* • Do you think there are any forces at the touching points of the chair and the ground (or floor)? • Is it easier to move the chair by lifting it or by dragging it? *This card aims to elicit children's ideas and explanations about dragging an object on the surface of the ground and identify some possible advantages for doing so*

Table 3.5: The focus questions and some relative *key questions* referring to the Pre-Intervention Interview cards.

It should be noted that there are no frictional phenomena in *'the book on the table'* instance. But, as it was indicated from the pilot interviews[5], the children had some difficulties in understanding the *'book on the tilted table'* instance. Thus, it was considered that an "introductory card" was needed for a better comprehension of the latter instance. This is how the *'book on the table'* instance was used in the pre-intervention interviews, although it also revealed some interesting conceptions about "weight", "gravity" and the "resistance" or "reaction" of the table (cf. § 4.1.b and § 5.1.a).

In the post-intervention interviews some *'explanatory questions'* were used in order to probe and investigate children's conceptions of friction and frictional phenomena. Some of these explanatory questions, together with the purposes of using these cards in the post-intervention interviews, are presented in the table that follows (Table 3.6).

[5] Two or three pilot interviews were conducted in each country respectively, in different schools from the ones that the two studies took place.

Interview Cards	*Focus questions and relative explanatory questions*
	*Is there any friction here?* • Where do you think that friction exists? • Can you describe it a bit? (how the shoes are rubbing, touching the ground etc.) *This card aims to elicit children's conceptions of friction in their attempt to explain how the person manages to walk rather than slither or side (as on ice)*
	*Do you think friction is keeping it (book) there?* • Where do you think that friction exists? • How do you think that friction exists at the touching points of the surface book and the surface of the table? • What will happen if the table is lifted a bit higher? • Will there be any friction if the book starts sliding down the table? *This card aims to elicit children's conceptions of friction in their attempt to explain how the book remains stationary on the surface of the tilted table, but also to express their opinion about the existence of friction when the book starts sliding on the surface of the tabletop*
	*Do you think friction keeps it there?* • Where do you think that friction exists? • Why do you think that the block does not slide along the surface of the table? • What will happen if we put more weight in the tray? • Is there any friction when the block is sliding? *This card aims to elicit children's conceptions of friction in their attempt to explain why the block remains motionless on the surface of the table, but also to express their opinion about the existence of friction when the block starts sliding on the tabletop*
	*Do you think there is any friction here?* • Where do you think that friction exists? • What will happen if the slope is lifted a bit higher? • Will there be any friction if the box starts sliding? *This card aims to elicit children's conceptions of friction in their attempt to explain how the box remains still on the surface of the slope, but also to express their opinion about the existence of friction when the slope is lifted a bit higher and the box starts sliding*
	**A.** *Do you think there is any friction here?* • Is there any friction when the person is sliding? • Where do you think that friction exists? • How do you think it is created? *This card aims to elicit children's conceptions about the possible existence of friction when a person goes down the slide*
	**B.** *Do you think there is any friction here?* • Where do you think that friction exists? • How do you think that the person remains stationary up on the slide? • Where do you think that there is more friction, in A or in B situation? *This card aims to elicit children's conceptions about the possible existence of friction when a person remains unmoved by holding steady with the hands pressing on the slide*

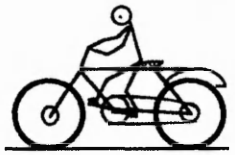
	*Do you think friction slows down the bike?* • Where do you think that friction exists? • Why does the bike slow down and eventually stop? • What happens at the touching points of the tyres and the ground? *This card aims to elicit children's conceptions of friction in their attempt to explain why the bicycle slows down and eventually stops*

Table 3.6: The focus questions and some relative *explanatory questions* referring to the Post-Intervention Interview cards.

It should be noted that the word "exist", at the end of the questions, was mostly used in the interviews in Greece, whereas expressions like "there is" or "is there?" were mostly used in the respective explanatory questions in England. This didn't seem to create any difficulties in the understanding of these questions and the children were able to express their views without problems of interpreting the questions (cf. relevant interview analyses that follow).

3.7. The transcription of interviews

The transcription of interviews is not an easy task. On the contrary, it proved to be challenging and time consuming. The transcriber has to confront several difficulties even though the primary concern of this approach is on the accuracy of the presentation of the content of the speech, while the representation of the intonation or pitch seems to be relatively unimportant (Watts, Harrison & Gilbert, 1982). The discussion that takes place during the course of this kind of interview is discontinuous and it is often interrupted or even punctuated by facial gestures, laughter, coughing, faltering and irregular pausing. The conversation is rather difficult to follow since it is full of inconsequence, anacoluthic statements [6], confusion and/or contradiction. It is quite possible that the interviewee is distracted for some reason, like some loud noise form the class next door or even the presence of the tape recorder itself. This kind of distraction tends to reinforce the inconsequence of the conversation although there had always been always an attempt to avoid such effects. Bearing in mind all

[6] A statement, sentence or construction which lacks grammatical and often logical sequence can be called "anacoluthic" (from the Greek *anacoluthon*: not following any form of sequence)

this composite context of the interview discourse, it is inevitable that the transcription of an interview becomes an interpretative activity, since what is written is considerably selective (Watts, 1983a, p. 2.33). It can also be argued that the transcription of an interview becomes "*a translation prepared by the transcriber*" (Gilbert, Watts & Osborne, 1985, p. 18) (cf. Appendix IV [7]).

All of the tape recordings used in this inquiry were transcribed by the interviewer who acted a twofold role of the transcriber and the analyst. The two-phase-approach described by Watts, Harrison and Gilbert (1982) was adopted for the transcription of the interviews. During the first phase the transcriber went through the entire tape recording and put down words and noises verbatim. The main focus was on the sounds, but hesitations, pauses, laughs, sights, coughs etc. were also included. During the second phase, the tape was replayed and intonation and comments were added, often with the aid of some notes that were kept while the interviews were conducted. All the interviews were transcribed in the language that they were conducted. Therefore, the interviews that were conducted in Greece were transcribed in Greek (cf. samples of interview transcripts in Appendix V).

One important parameter that has to be kept in mind is that no matter how accurate or well-annotated a transcript turns out to be, it is always a level beyond what actually occurred during the course of the interview. As Watts, Harrison and Gilbert (1982) put it, "*transcripts must provide basic data for detailed study and it is important to remember that they are not raw data, but represent the 'transcriber's-eye-view' of the actual event*" (p.11).

3.8. The analysis of the interview data and some relevant considerations

In the present inquiry and for both studies, the interview analysis is conducted in two phases and two levels. Hence, the first phase is the analysis of the pre-intervention

[7] In Appendix IV there is information on the style, notation and format of the interview transcripts.

interviews and the second phase is the analysis of the post-intervention interviews. Both of these phases constitute the first level of analysis which is about learners' alternative conceptions which are related to the depicted instances of the interview cards. The second level of analysis refers to a comparison and interpretation of the pre-intervention and post-intervention interviews of two learners in each study, on the basis of anticipated conceptual change. Each learner constitutes a case and some aspects of his or her conceptual change, about friction and frictional phenomena, are highlighted, commented and interpreted.

For both of the phases of the first level of the analysis each interview transcript was at first read carefully to gain some general understanding of the learner's conceptions. Then each interview (pre-intervention and post-intervention) was separated into a number of parts, each time equivalent to the number of the interview cards and the learners' responses for each interview card were analysed. Each response was treated seriously, whether it was more difficult to be interpreted or not.

The first step of the analysis was to take a single transcript and analyse the learner's responses to certain instances, or relevant questions which referred to some aspects of the instances (cf. § 3.7). Thus, some inferences were made for the learner's conceptions for each depicted instance and they were recorded. Then a second transcript was taken and the same process was followed. After that, the same with a third transcript and so on. This process formed tentative groupings of conceptions that were checked and reconsidered after each transcript was brought into the pool. In this way all of the statements, or children's utterances, are accounted for, and the analysis refers to conceptions from all of the learners involved in each study respectively.

The analysis of each card aimed not only to construct groupings of conceptions, but also to highlight some interesting alternative conceptions that could not be included in any of the groupings. It should be noticed here that the term "groupings" is used instead of the term "categories" for the following reasons:

- The number of learners in each study is too small (nine in England and ten in Greece) to claim that "categories" of responses are to be constructed.

- Usually, when responses are "categorised" certain criteria are used in terms of frequency of appearance of a certain response of an individual within an interview or a series of interviews. For example, Engel (1982) limits categories to one response per question for each interviewee, but she also admits that it was common for different parts of responses to fit into different categories. In this inquiry such criteria are not established or used in the analysis of the interview data, which is mainly conducted on the basis of "grouping" responses which are construed to have similarities in the meaning of the utterances they refer to. Hence, they are mostly groupings of responses referring to particular questions or certain parts of the flow of the conversation in the interviews.

- The term "grouping" is preferred to the term "category" because it appears to be more flexible, without the rather rigid denotations of the term "category".

In this sense, the groupings of conceptions were not ascribed any labels or headings, but were described with propositional statements instead. Nevertheless, these groupings of conceptions "are not individualised and present an interpretation of statements at general, but functional level" (Watts, 1983a, p. 4.15). Furthermore, some "alternative conceptions", that could not be included in any of the groupings, are presented and interpreted in terms of "personalised constructions of an individual" (Watts, 1983a, p. 4.10). Hence, the term conception is used "to describe talk and accepted meanings which are entirely idiosyncratic or generaliseable - in fact anything that is attributable to a single person" (ibid.). Alternative conceptions are presented at the end of the analysis of each interview card.

The second level of analysis aimed to overview and compare children's conceptions from the pre-intervention and the post-intervention interviews, in order to reveal some aspects of their conceptual change (cf. § 4.5 and § 5.5 respectively).

Although firm criteria were not used in the construction of "groupings of conceptions", certain "warrants" were kept in mind in the construction of conclusions

and the development of subsequent arguments about children's conceptions and conceptual change.

Lythcott & Duschl (1990) refer to Toulmin's (1969) ideas about the four pieces of an argument (*data, conclusions, warrants* and *backings*) to point out that a sound argument would show how conclusions are drawn from the data via warrants, which are supported by backings. Thus, if the data are sound, and if the warrants are legitimated by the authority of acceptable backings, then the interpretation drawn from a certain research project should be, at least, granted (Lythcott & Duschl, 1990).

As Toulmin (1969) refers to them, *warrants* are assumptions or propositions that allow one to move from data to conclusions. They function as guarantees that authorise the steps one takes towards defensible conclusions. Hence, "data is what we have to go on, warrants is how we get there" (Lythcott & Duschl, 1990). Usually, a warrant has a general hypothetical form which is similar to a major premise. Warrant-using arguments, are arguments that move from data to defensible conclusions, via warrants.

In this context Lythcott & Duschl (1990) [8] present three warrants which are used, as they claim, in the development of arguments generated from interview data in the field of science education. These warrants have been considered seriously in conducting the interviews and analysing the interview data in the present inquiry. Thus, they are as follows:

- Novel verbiage used by the interviewee, (verbiage that has not been introduced into the conversation by the interviewer) reflects part of the learner's cognitive system, that is what he or she knows.
- Words with scientific meaning, may only have the meanings ascribed to them which are given in the conversation by the interviewees, whether introduced by

[8] Lythcott & Duschl (1990) use the term "verbiage" to refer to "what the children are saying" and in this respect the term has been maintained here, in the analysis of their theoretical approach.

the interviewer or the interviewee; common meanings, scientific or otherwise, may not be inferred.

- When verbiage of children, from interviews, is compared to segments of public domain science knowledge, goodness of fit can be assessed; thus, verbiage that can be argued as being consistent in meaning with public domain science knowledge can be said to arise from that learner's scientific conceptions, or if the opposite happens, then it can be asserted that the meaning arises from the learner's non-scientific conceptions. (ibid.)

It is not claimed that these warrants are explicit or that they constitute an exhaustive set, but it is stressed here that they are kept in mind in order to express defensible knowledge claims. It is suggested though, that the theoretical framework presented in Chapter 1 constitutes a set of "backings", or "world views" behind the warrants expressed above (Lythcott & Duschl, 1990).

On the whole, the analysis of the interviews is "an act of constructive interpretation" (Powney & Watts, 1987, p. 158). Thus, the interview data may be construed in several alternative ways and several alternative analyses may be constructed. Furthermore, it depends on what one is after and it should be kept in mind that the "research report is the interviewer's story of the interviewee's story" (Powney & Watts, 1987, p. 193).

3.9. The research design

Within the framework of this inquiry, two studies were conducted, one in England and one in Greece respectively. The educational setting was one class of children in each country. Hence, the study in England was conducted with one class of Year 6 children (21 pupils), whereas the study in Greece was conducted with an E' Grade (23 pupils) of a primary school. A teaching intervention, with a series of three and two sessions respectively, was organised and conducted in each country. Some children (9 in England and 10 in Greece) were interviewed before and after the teaching

interventions in order to investigate their conceptions about friction and frictional phenomena. Some more information about children's conceptions was also drawn from assessment materials such as "drawing and writing" tests and concept maps (cf. §§ 4.2.6., 4.3., 5.2.4., 5.3.). Some aspects of conceptual change of two cases of children in each study are highlighted and discussed at the last section of each study (cf. § 4.5 and § 5.5). Most of the features of the research design, together with some information on the analysis of the interview data are presented in fig. 3.5 that follows.

The research design, with the two phases and the two levels of the interview analysis

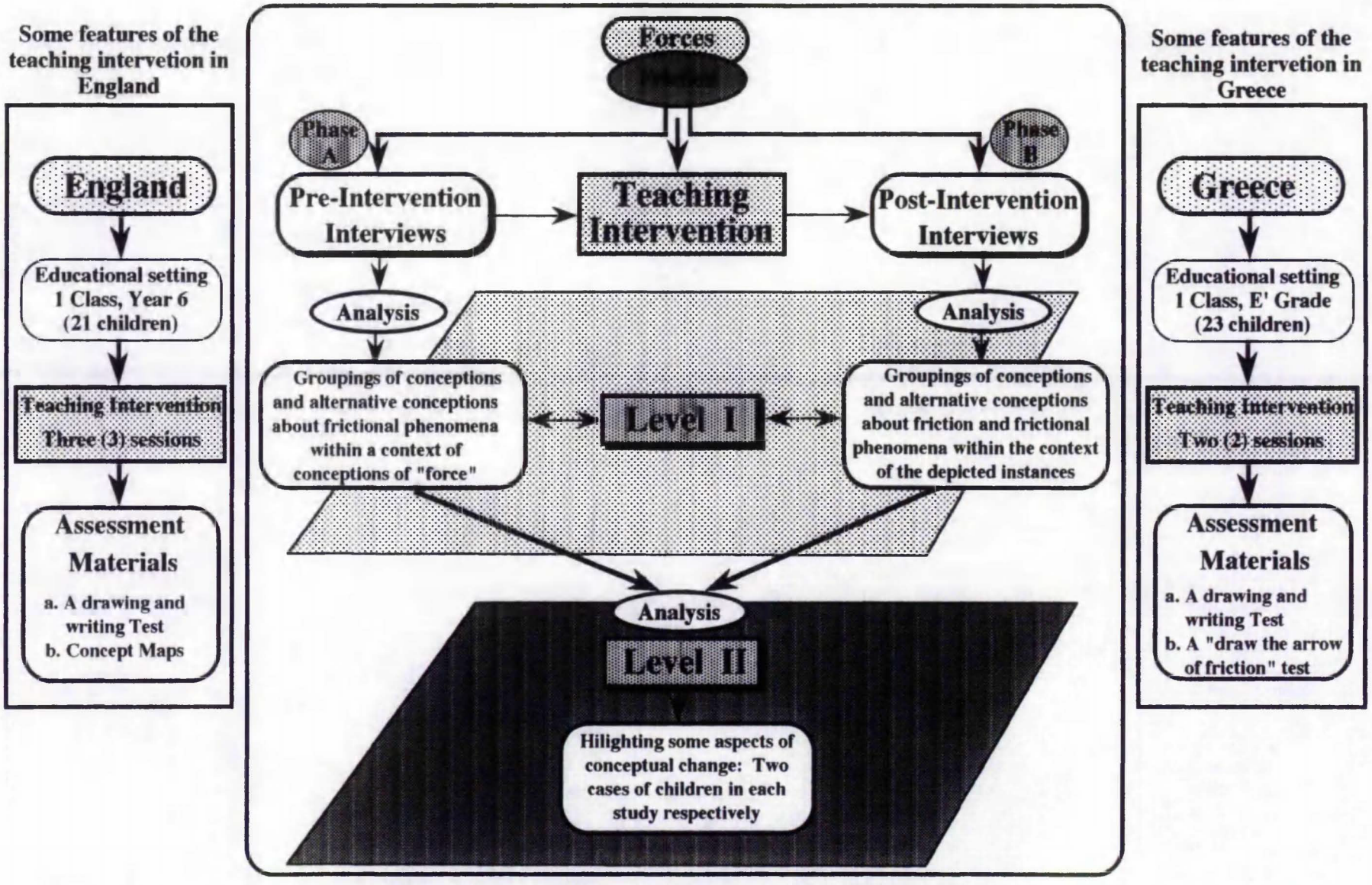


Fig. 3.5: A schematic representation of the research design and some fetures of the teaching intervention in England and in Greece

CHAPTER 4

The Study in England

4.1.0. Pre-Intervention Interview Analysis (England)

The purpose of the pre-intervention interview analysis is to identify, present and interpret groupings of conceptions and alternative conceptions, about frictional phenomena held by the children of this study, before the teaching intervention and within a context of conceptions of "force". Each card is treated separately while a more general overview and discussion is written at the end of this analysis.

For both of the pre-intervention and the post-intervention analyses, speech marks are used to refer to the children's authentic utterances. Furthermore, it is frequently attempted to put "anacoluthic statements" into a logical or commonsensical sequence, according to the interpretation of the analyst, of course. This is done by matching together pieces of anacoluthic or discontinuous talk, within the same utterance or between different utterances that refer to the same or similar, in meaning, issues. The numbers in parentheses that follow to document the analysis, refer to the respective utterance numbers as they appear in the extracts from the interview transcripts. At the end of the analysis of each card there is a table which summarises the groupings of conceptions and some alternative conceptions which refer to the respective instances depicted on the cards. The nine (**9**) children that took part in this interview process are identified by the first two letters of their names (or three, in the one case, where they were the same).

4.1.a. The card with 'the man pushing the car' instance

*Three children (**Jo, An, Ia**) appear to be considering a notion of "grip" at the touching points of the car tyres and the ground. They do not seem to regard that as a force and they suggest that the car does not move because the man is not strong enough.*

(**Jo**) appears to be considering a notion of "grip" on the shoes of the man that are touching the ground and manage hold him there without slipping (011,5). She also recognises some grip on the tyres , but she appears to generalise that as a characteristic of the tyres (013). She doesn't seem to think of grip as a force and she probably sees it as something that is "just happening" (015). She suggests that the car doesn't move either because of the grip or because the "man is not pushing hard enough" or "it could be both really" (017).

011.5 **Jo** **>>** .. also the man's legs are pushing away .. his shoes are gripping on the ground .. so .. he can push really .. and not just slip and fall down .. *(laugh)* the shoes push on the ground and hold him there ..
012 **Int** all right .. do you think there are any forces at the touching points of the wheels and the ground .. /
013 **Jo** umm ..4.. there must be a bit of grip there as well .. maybe that grip.. that grip makes it difficult for him to move it .. you know.. there's always grip on the tyres..
014 **Int** is that .. grip .. a force then .. /
015 **Jo** umm .. no you can't really call that a force.. the tyres .. his shoes also.. are just gripping on the ground..
016 **Int** I see.. do you reckon that this grip could be the cause that he can't move the car .. /
017 **Jo** well sort of .. I am not really sure.. it could be that or also the fact that he is not pushing hard enough.. or it could be **both** really .. /

(**An**) seems to recognise the force from the man, gravity and a notion of "resistance" from the ground[1] (071). He appears to be thinking about the grip as a characteristic of the tyres which ensures people's safety and prevents the car from sliding on the surface of the road (073). He doesn't seem to regard grip as a hindrance for the man to push the car and he suggests that the car remains motionless because the man "is not strong enough" (075).

071 **An** yeah .. I see.. but he still can't move it.. so we have him pushing it ... gravity pulling the car down .. and resistance from the ground..
072 **Int** all right .. do you think there are any forces at the touching points of the wheels and the ground .. /
073 **An** umm .. well the car tyres have got to have grip.. you know.. they've got to have good grip for roads .. you know.. to keep.. that keeps you safe.. and the car doesn't slide all around the place..
074 **Int** do you think that this grip makes it difficult for the man to move the car .. /
075 **An** no .. not really .. 'cos I just think he is not strong enough to move the car.. *(laugh)*..

*Along this line of thinking, there are two children (**Ha, Is**) who seem to regard the physical inability of the man to move the car as the main reason for the motionless*

[1] (**An**) refers to "resistance" as a characteristic of the supporting medium (floor, table) throughout his interview, cf. analysis of the 'book on the table' instance.

condition of the car. They appear to be describing some other forces like gravity and the man's push, but they have some difficulties in explaining why the car remains unmoving.

For example (**Ha**) indicates that there is a force from the man (010), the force of gravity which is actually "pushing" the car on the ground (012) but she doesn't seem to be considering any forces at the touching points of the wheels and the ground (014). She seems to be a bit puzzled about the motionless condition of the car and when a possible explanation concerning "the brakes being on" is rejected (016 & 017), she turns to the physical inability of the man to push it hard enough (018). She goes on to suggest that if he was a weight-lifter he would be strong enough to push the car.

010	**Ha**	a pushing force ... at the back of the car ... the man is pushing it .. that's a force..
011	**Int**	umm hmm .. any other forces here .. /
012	**Ha**	er ..6.. gravity pushing the car on the ground.. that's another force on the car .. pushing it on the ground..
013	**Int**	yeah .. do you think there are any forces at the touching points of the wheels and the ground.. /
014	**Ha**	er ..6.. no I don't think so..
015	**Int**	all right .. the man is pushing the car but it is not moving .. can you explain .. why does this happen .. /
016	**Ha**	er ..4.. is it because the brakes are on .. / *(laugh)*
017	**Int**	oh.. no .. the brakes are not on right now..
018	**Ha**	well he is not pushing hard enough really.. say if he was a weight lifter.. he might .. he could move the car.. but he .. he is just not strong enough to move it ..
019	**Int**	all right .. I see ..
020	**Ha**	that's what I reckon ..

(**Is**) appears to be recognising the force from the man (017), gravity (020) and a notion of "reaction" from the ground[2] (023), but she can't provide an explanation for the motionless condition of the car. Eventually, she also suggests that the man "is not strong enough" (025).

017	**Is**	he is pushing it but it is not moving..
018	**Int**	yes.. do you think there is any other force.. say from the earth on the car.. /
019	**Is**	it's str .. it's.. it's flat.. so it's not .. umm ..6.. gravity .. /
020	**Int**	gravity.. yeah.. do you think there are any sort of forces on the tyres.. /
021	**Is**	is it that reaction thing.. /
022	**Int**	reaction .. what do you mean .. /
023	**Is**	reaction from the ground ..
024	**Int**	reaction from the ground.. all right ..4.. but since you say that the man is pushing the car but the car is not moving.. can you explain why this happens../
025	**Is**	umm ..6.. dunno.. 4.. well .. he is not strong enough.. *(laugh)*..

[2] **(Is)** using the word "reaction" throughout her interview with a rather poor understanding of the term, cf. analysis of the 'book on the table' instance.

*Two children (**Da, Ph**) seem to suggest that gravity is the reason for the stationary condition of the car. They suggest that gravity somehow holds the car motionless on the ground, "sucking", or "forcing" it to stay there.*

(**Da**) appears to be recognising the force from the man who is pushing the car with "his strength" (085). Then he attempts to explain the fact that the car is not moving by saying that the wheels are held down onto the ground due to gravity (087 & 089), which he sees metaphorically as "a big Hoover" that sucks everything onto the ground (091).

085 **Da** well .. it's the man actually with his strength pushing the car .. that's one force..
086 **Int** yeah.. but the car is not moving ..
087 **Da** well .. the wheels are like .. being held down onto the ground..
088 **Int** how do you think that happens.. /
089 **Da** er ..4.. with gravity..
090 **Int** in what way do you think gravity holds the wheels down onto the ground .. /
091 **Da** in what way.. /.. 'cos it's like a big Hoover that sucks everything down onto the ground ..

In a similar way, (**Ph**) suggests that there is more gravity "forcing" a lorry down to the ground than a vehicle made of wood which, as he claims, would be rather light (019). Thus, it is quite possibly suggested that gravity is "pulling" the car down to the ground and somehow it is "forcing it" to remain unmoved.

018 **Int** but the car is not moving .. do you think there is any other reason for that .. /
019 **Ph** yeah ... because there is more fo::rce .. if I was trying to push a car... like it was made of wood .. it was quite light.. with wheels it'd move .. but if I was trying to push a lorry which is about ten tons it wouldn't move 'cos you've got more gravity forcing it .. pulling it down to the ground..

*Two children (**Pa, Ia**) seem to be thinking in terms of "imaginary forces" which are hindering the movement of the car. They appear to be exerted in the front part of the car or on the wheels.*

(**Pa**) appears to be considering an imaginary force "coming at" the car from the opposite direction of the man's push (124) which is exerted in the front part of the car (126) and the man "can't push against that force" (128). He goes further to suggest that this force is somehow related to the wheels of the car because it has "come and stayed" on them and this hinders them from going round (130 & 132). He doesn't explain, though, what this force is . It just seems to exist there.

123	**Int**	yeah .. but in this situation the car is not moving .. he is pushing it but it is not moving ..	
124	**Pa**	well there's a force coming **at** it from the other side..	
125	**Int**	where does that force act.. /	
126	**Pa**	umm .. I think on the front of the car..	
127	**Int**	yeah.. what do you mean .. /	
128	**Pa**	because like.. he is pushing but there's a force from that side .. so he can't push against that force ..	
129	**Int**	umm hmm .. do you think the wheels have anything got to do with this.. /	
130	**Pa**	yeah.. because .. it's like the force is coming so.. the wheels are not moving... so it's just like stationary.. because the force is on the wheels .. there .. it's like come and stayed on the wheels.. 'cos it can't go passed this so it stayed there .. then the car can't move the wheels can't go around.. so.. that's what I think..	
131	**Int**	so .. do you mean that .. the force that is coming from this direction .. as you say.. is just stopping the wheels there .. /	
132	**Pa**	yeah .. it's stopping the wheels going round ..	

(**Ia**) appears to be thinking in terms of a set of forces that act in the opposite direction (on the right) of the push of the man (on the left) and somehow they seem to be "reacting" as if they are pushing (180). He suggests that the forces are exerted in front of the engine, in front of the screen and under the wheels (184-191).

180	**Ia**	yeah .. and he is trying to push it that way .. and the force reacts .. when .. as if it looks like pushing ..	[pointing to the left]
181	**Int**	which force reacts.. /	
182	**Ia**	the one that is going that way ..	[pointing to the right]
183	**Int**	yeah .. and where do you think that force exists in which places .. where .. /	
184	**Ia**	well .. there.. and there .. on the surface there .. there and there and on the way up there and there ..	[pointing under the wheels, in front of the engine and in front of the screen]
185	**Int**	so .. do you mean under the wheels .. /	
186	**Ia**	yeah..	
187	**Int**	but also there in front of the engine	
187.5	**Ia**	**>>** yeah it's pushing that way..	[pointing to the right]
188	**Int**	.. and there in the front part of the car.. /	
189	**Ia**	yeah .. also..	
190	**Int**	all right is that how you think the forces are .. /	
191	**Ia**	yeah .. the forces that push it *(the car)* that way..	[pointing to the right]

He discusses his view further by suggesting that the force pushing to the right and the man's force are somehow "matching" each other and as a result the car remains still (197). He doesn't explain, though, what the nature of this opposing force is.

195	**Ia**	well that force pushes it *(the car)* that way and there's a force pushing it along.. the opposite way.. and it'd stay still..	[pointing upwards and then to the right]
196	**Int**	do you mean from the opposite way of the man's force.. /	
197	**Ia**	yeah .. so that's pushing it that way.. and he is trying to push it that way and that 'd stay still *(the car)* .. 'cos that matches it.. matches the force .. in a way or so ..	[pointing to the right and then to the left]

There is only one case of a child (**Ph**) who seems to recognise some "slight friction" on the tyres as the man tyres to push the car, in parallel with some pressure exerted on

them (013). He appears to believe that this slight friction exists "on the bits of the wheels that are actually touching the ground" (015).

013 **Ph** yeah .. there'll be pressure on the car.. I mean on the wheels and stuff .. and there'll be *(cough)* .. and there'll be pressure on the tyres when you try to push it like if they 're not going to move .. he is trying to move it but they don't ... friction around about there .. ish .. [pointing under the wheels]
014 **Int** where do you think friction exists here .. /
015 **Ph** well .. on the wheels basically.. on the bits of the wheels that are actually touching the ground ... not a very much of it .. a slight friction ..
016 **Int** a slight friction .. /
017 **Ph** yeah..

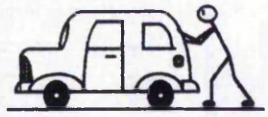
Interview Card	*Groupings of conceptions and alternative conceptions*	*NoR*
	• **There is some "grip" at the touching points of the wheels and the ground but it's not really a force.**	*3*
	• **The man is not strong enough to push the car forward**	*2*
	• **Gravity somehow holds the car motionless by "pulling" it downwards or "forcing" it on the ground**	*2*
	• **There are "imaginary forces" exerted in the front part of the car and on the wheels hindering its potential movement**	*2*
	• **There is some "slight friction" at the touching points of the wheels and the ground**	*1*

Table 4.1.1: A synopsis of the groupings of conceptions and alternative conceptions from the analysis of the "man pushing the car" instance with respective numbers of children's responses (*NoR*).

4.1.b. The card with 'the book on the table' instance

Most of the children recognise the force of gravity as a pulling force on the book and on the table. Only (**An**) seems to make a distinction between "weight" and "gravity" in the two cards that refer to the book on the table instances.

*Five children (**Ha, Da, Jo, And, Pa**) appear to express the view that there are no forces from the table towards the book and most of them provide their own reasoning.*

For example (**Ha**) appears to recognise the force of gravity as a pushing force which pushes down the book on the table. She seems to reason that by hypothesising that if the book was in space it would float up (028). However, she does not think that there is any force from the table towards the book (030).

024 **Ha** there's a book on the table .. do you think there are any forces here.. / .. er ..6.. well there's a force on the table .. 'cos the book .. the book is on it .. so it's pushing it down..
025 **Int** umm hmm..

026 **Ha** and that's gravity .. I think .. because the book is pushing on the table *(cough)*
027 **Int** yeah..
028 **Ha** and .. *(cough)* umm ..4.. if it was say.. like .. in space it would float up.. so it's now pushed down by gravity..
029 **Int** umm hmm.. do you think there are any forces from the table towards the book.. /
030 **Ha** er ..6.. from the table ..4.. no I can't think of any force there.. the book is just pushing the table.. *(laugh)*..

Similarly (**Da**) has the opinion that there is no force from the table towards the book (057). However, he seems to ascribe a supporting role to the table, which he describes as a "solid thing" that cannot be passed through (055). Thus, he refers to an aptitude of the table or the material of the table, without any possible acknowledgement to an upward force.

049 **Da** there is a book on the table ... do you think there are any forces here... / .. same again... it's gravity which is pulling it ..
050 **Int** umm hmm ..
051 **Da** er ..4..
052 **Int** why do you think the book stays on the table .. /
053 **Da** umm.. it's because of gravity.. and if there weren't .. the table the book would fall straight down...
054 **Int** yeah.. I see..
055 **Da** a bit like.. it can't really go through the table .. 'cos the table is like a solid thing and the book can't pass through the table.. *(laugh)*
056 **Int** yeah.. all right .. do you think there is any force from the table towards the book .. /
057 **Da** er.. no I don't think so ..

(**Jo**) refers to a pushing force on the book and various parts of the table which seems to be gravity (023 & 025), but she doesn't think that there is a force from the table towards the book. She appears to be considering that the book stays on the table because the table is "flat" and "stilted", so the table is just holding it there since the book cannot go down through it (027 & 029).

023 **Jo** the book is pushing on the table.. and also the legs of the table are pushing on the ground.. and also the top of the table is pushing on the top of the legs.. like a force .. it's pushing them as well.. [pointing to all the respective parts of the book and the table]
024 **Int** umm hmm .. any other forces here .. /
025 **Jo** er .. gravity .. gravity is actually pulling everything down..
026 **Int** all right .. do you think there is any force from the table towards the book .. /
027 **Jo** well .. the book .. er.. it stays on the table because it is flat.. if it wasn't **stilted** .. then the book probably would go down through it onto the ground..
028 **Int** yeah .. is that a force then.. /
029 **Jo** er.. no .. I don't think so .. the table is just holding it there .. that's all ..

*Two children (**Ia, Ph**) appear to be holding a conception of an upward force from the table towards the book or from the floor towards the legs of the table.*

(**Ia**) seems to recognise that there are forces pushing downwards and he names them as "gravity" (046). Furthermore, he appears to be considering forces pushing upwards at the legs of the table and from the table towards the book, although he says that he doesn't have a name for them (052).

042	**Ia**	yeah.. pushing it ..gra.. there's gra.. /.. a pushing down force .. and on the table .. forces pushing the table.. yeah .. and there is also a push on the table that way ..	[pointing towards the floor] [pointing from the floor towards the table]
043	**Int**	from the floor .. you mean.. /	
044	**Ia**	yeah..	
045	**Int**	all right .. how would you call the forces that push downwards .. /	
046	**Ia**	downwards .. / umm ..4.. gravity is pushing it downwards..	
047	**Int**	yeah .. /	
048	**Ia**	yeah ..	
049	**Int**	and have you got any names for the forces pushing upwards.. /	
050	**Ia**	umm .. no I don't know it .. *(laugh)*	
051	**Int**	you .. don't know it but you feel that there are forces pushing upwards	
052	**Ia**	yeah at the book there .. and at the table as well..	[pointing under the book and at the legs of the table]

(**Ph**) appears to be placing a lot of emphasis on the fact that "everything is pulled down" (060) and that gravity is pulling the book "straight down". Although he initially seems to hold the view that there is no upward force from the table towards the book (064) he seems to be changing his mind later on in an attempt of the interviewer to probe him to explain his view. Thus, he refers to a "table force" (066) which is pushing against the book, or to "two equal forces" (067,5). He appears to have shifted his initial expression and he seems to have accepted the interviewer's probe that the second view is a better explanation (071).

059	**Int**	any forces pushing up .. /	
060	**Ph**	everything is pulled **down** .. ***..	
061	**Int**	all right why does the book stay on the table then .. why doesn't it go around../	
062	**Ph**	well it can't really go around.. because gravity is pulling it **down.** straight down	
063	**Int**	well .. do you think there's a force from the table towards the book .. /	
064	**Ph**	umm.. there's no force of the table holding it up.... and if it didn't hold it up it would crash into the table and onto the floor .. anything like that..	
065	**Int**	all right .. so is there a force then .. /	
066	**Ph**	well it's the gravity force and it's the table force .. that just makes it *(the book)* stay there.. it's like the table is pushing against there .. and gravity is pulling the book downwards.. so it usually stays there.. \	[pointing under the book]
067	**Int**	right.. but are there two forces now...	
067.5	**Ph**	>> yeah two equal forces ..	
068	**Int**	.. and what you say now is not what you said in the beginning .. is it .. /	
069	**Ph**	no..	
070	**Int**	do you think that this is a better explanation then.. /	
071	**Ph**	yeah.. / I think so ..	

Later on, during the course of the interview, (**Ph**) refers to a "support" from the ground towards the legs of the table or the things that are on the tabletop and he

seems to think of this "support" in terms of a force because it is somehow pushing the table up (082).

075	**Int**	.. yeah I mean .. do you think there is a force from the ground towards the legs of the table.. /
076	**Ph**	yeah.. the ground is supporting it a lot.. \
077	**Int**	what do you mean.. supporting it.. /
078	**Ph**	yeah a lot of support from the ground.. like.. the table .. if there was no ground the table would just fall and fall and fall ..
079	**Int**	all right...
080	**Ph**	but since the ground is there it can't really go through 'cos it is supporting it .. like all this stuff on this table which are not falling or .. er.. 'cos the table is supporting them ... and the ground is supporting the table..
081	**Int**	all right and .. that supporting do you think that it is a force.. /
082	**Ph**	yeah .. 'cos it's sort of pushing it up ..

*Two children (**Is, An**) seem to be holding rather ambiguous conceptions of "reaction" or "resistance" from the table towards the book.*

(**Is**) indicates that gravity is keeping the book on the table (052) but she also senses that there is a "reaction" from the table supporting the book (056), but she seems to be uncertain and rather confused about it being a force (058).

050	**Is**	gravity ...	
051	**Int**	gravity ... what is it doing.. /	
052	**Is**	keeping the book on the table ..	
053	**Int**	all right... any other forces here.. /	
054	**Is**	mm.. reaction .. \	
055	**Int**	reaction .. what do you mean .. /	
056	**Is**	umm .. 4.. there from the table .. \	[pointing upwards from the table towards the book]
057	**Int**	do you mean reaction from the table.. /	
058	**Is**	yeah .. that's what I mean.. er .. the table supporting it *(the book)* .. sort of ..	

(**An**) refers to "resistance" from the table (038), but she seems to be differentiating between "weight" and "gravity" which he views as two different forces. She seems to be holding the conception that since the book is "heavy for what it is" it "adds to the ease of gravity pulling it down" (040), which is something that wouldn't happen if it was lighter. His conception of weight appears to be lying between the adjectives "light" and "heavy".

038	**An**	there's a book on the table.. do you think there are any forces here .. /.. umm.. there's the weight and gravity pulling it and the resistance of the table.. er..
039	**Int**	what do you mean .. the weight and gravity.. are they two different forces.. /
040	**An**	well yeah .. say if the .. the book was very light .. gravity would still be a force on it.... but if.. as there is.. umm.. as it is .. well quite heavy for what it is.. it adds to the ease of gravity pulling it down..
041	**Int**	umm .. I see .. so these are two different forces .. weight and gravity.. /
042	**An**	yeah..

Later on, he mentions that the table just resists the book from going down but he doesn't seem to view this resistance as a force (046).

045 **Int** umm hmm.. I see.. that's interesting .. you also mentioned something about the resistance of the table earlier.. what do you mean .. /
046 **An** yeah.. the table umm .. it just resists the book from keep.. from keep going down to the ground..

Interview Card	Groupings of conceptions and alternative conceptions	NoR
	• **There is no upward force from the table towards the book or from the floor towards the legs of the table.** • **the table is like a solid thing** • **the table is flat and stilted** • **There is an upward force from the table towards the book or from the floor towards the legs of the table which supports the book and the table.** • **There is some kind of "resistance" or "reaction" from the table towards the book or from the floor towards the legs of the table which doesn't seem to be a force.**	*5* *2* *2*

Table 4.1.2: A synopsis of the groupings of conceptions and alternative conceptions from the analysis of the "book on the table" instance with respective numbers of children's responses (*NoR*).

4.1.c. The card with 'the book on the tilted table' instance

*Three children (**Ia, Da, Ha**) appear to be considering that the reason why the book remains stationary on the table depends on the surfaces or "substances" (**Da**) that are in contact with each other. Furthermore, they appear to be thinking of that as an external or internal characteristic of the surfaces.*

(**Ia**) seems to be reasoning that the book stays on the table because of its surface (069) or because of the surface of the table (074). He describes the latter as "uneven" (074) or a "hard surface" (076) and he appears to be thinking of it metaphorically, in terms of a tyre which has "grips" and it "is getting into the ground" (078) and stops the book from sliding (080).

068 **Int** yeah .. and why do you think that it stays there.. /
069 **Ia** because the surface of the book .. is it.. /
070 **Int** the surface .. yeah .. let's see..
070.5 **Ia** >> it could be that.. /.. or ..4..
071 **Int** .. it could be.. which surface .. of the book or of the table .. /
072 **Ia** the one that is on the table .. the table surface ..
073 **Int** yeah .. the surface of the table .. what about the surface of the book .. that is touching the surface of the table ..
074 **Ia** umm.. yeah the surface ..5.. it's uneven like...it might not go along *(laugh)*..
075 **Int** O.K ... what do you mean it might not go along .. /

076 **Ia** well it is like.. er.. like .. er ..4.. if it is like hard surface ..
077 **Int** umm hmm ..
078 **Ia** it's.. like a tyre it's got .. you know.. grips like...and it is getting into the ground..
079 **Int** umm hmm ..
080 **Ia** and it stops it sliding ..

Later on, when he is asked what would happen if we lifted the table a bit higher, he wonders if the book would slide (098) and he mentions that it might, but he also infers that "it depends on the surfaces" (099).

097 **Ia** yeah .. if it's rough .. and you pull it a bit higher
097.5 **Int** **>>** umm hmm
098 **Ia** I wonder if it'd slide .. but.. *(laugh)*
098.5 **Int** **>>** umm .. yeah../
099 **Ia** ..if ..if .. you pull the table a bit higher it might.. all right .. / 'cos it depends on the surfaces ..

(**Da**) points out that the surfaces of the table and the book are touching (073) and then he goes on to suggest that books can have "ripply covers" (075). After that, he appears to be shifting to "substances" (077) in order to refer to different qualities of surfaces. Thus, he says he knows that "rubber can hold things", but plastic may let them "roll down" (077) and when he is asked if he thinks that the surface of the table has something to do with it, he answers affirmatively, repeating and explaining his view (079).

072 **Int** do you think there are any forces there ... where the surface of the cover of the book is touching the surface of the table .. / [pointing at the respective spot at the picture]
073 **Da** well. .. yeah.. it's touching .. ain't it... it's like ... are there any grips or anything on the book.. /
074 **Int** what do you mean .. /
075 **Da** well you know.. books can have like.. ripply covers.. can't they .. /
076 **Int** yeah .. do you think that could hold the book on the table.. /
077 **Da** er.. it might do.. it depends on the substances.. 'cos I know .. like rubber can hold things.. but if it was plastic or like.. like.. it would roll down..
078 **Int** do you think the surface of the table has anything got to do with it.. /
079 **Da** yeah.. because like .. as I say.. it's different substances.. this is like.. making roll off a lot easier.. or.. just hold it back there..

(**Ha**) seems to indicate the existence of an "imaginary force" from the left pulling the book upwards along the surface of the table (038), but she does not reveal where this force comes from and, as she claims, it "just helps the book stay there" (044 & 046). She suggests though, that if the table was lifted a bit higher then that "imaginary force", "wouldn't be able" to pull the book up any more and it would start sliding (040). Nevertheless, she appears to be distinguishing between a "rough" surface of a

book, in which case it could probably stay on the table longer and a "slippery" or a "shined" surface of a book (042) which would probably have the opposite effect on it. She also suggests that it could be the table that has a rough surface and "holds the book steady" (042).

038	**Ha**	er ..4.. a pulling force .. a pulling force from that side.. trying to keep the book there...	[pointing to the right, up the table]
039	**Int**	umm hmm .. I see..	
040	**Ha**	er.. well if the table was lifted a bit more higher.. then that force wouldn't be able to pull it up.. and keep it there .. any more.. and the book would slide down ..	
041	**Int**	yeah.. I see .. do you think there are any forces at the touching points of the book and the table ... /	
042	**Ha**	yeah .. it could have .. well if it was say .. rough then it could probably stay there for longer.. then if it was say a slippery one or a shined book ... or it could be the table that has a rough surface ... and it holds .. holds the book steady ..	
043	**Int**	all right .. I see.. do these relate to that pulling force you mentioned earlier .. /	
044	**Ha**	well .. no I don't think so that pulling force is another thing ...	
045	**Int**	what do you mean .. /	
046	**Ha**	er.. it's just a sort of pulling force there... I can't really explain it .. it just helps .. the book stay there ..	

*Two children (**And, Jo**) seem to be sensing a "special effect" of the surfaces which they call "grip" and they suggest that it could be the reason for the book to stay still on the surface of the table. Again this is seen as an internal property of the surfaces and there does not appear to be a conception of it as a force.*

(**And**) seems to suggest that due to the nature of its surface, the book can grip onto the table (063) and he takes for example a hardback leather book (065). He does not seem to have the same opinion for the surface of the table though (067).

063	**And**	yeah.. 'cos the book .. the book.. it might be just the grip of the book.. staying up on the table ..
064	**Int**	yeah .. what do you mean .. the grip of the book.. /
065	**And**	say if.. if it is like a hardback and it's got leather.. on the bottom.. it would grip onto the table..
066	**Int**	does that only happen .. on the surface of the book .. /
067	**And**	er ..6.. I don't know about the table..

(**Jo**) appears to be considering the view that the book doesn't slide because "the table is not steep enough" (033), but in the same utterance she suggests that "it could be the grip", which she seems to attribute to the cover of the book for being "rather rough". To highlight the effect of the grip, she is using the metaphor of "a brake" (035).

032	**Int**	yeah.. but why does the book stay there .. /.. and does not slide down ..	
033	**Jo**	er .. the table is not steep enough .. or it could be .. a bit.. it could be the grip there again ..	[pointing along the surface of the book that is touching the table]

034 **Int** the grip there you say .. can you explain that a bit .. /
035 **Jo** yeah .. the book.. the cover .. is rather rough and it could.. it could grip on the table.. and just hold itself there.. it's like a brake .. you know..

*Four children (**An, Pa, Is, Ph**) attempt to reason why the book stays on the tilted table by using a conception of gravity or "a downwards pushing force" which somehow "sticks" or "edges" the book onto the table. One child (**Ph**) indicates that there are two components of gravity, one vertical and one along the surface of the table and suggests that the book will start sliding if the first component gets stronger or the latter gets weaker, when the table is lifted a bit higher.*

(**An**) appears to be thinking in terms of gravity as a force which would either pull the book downwards along the table if it was "more steep", or it would help it stay in its place (050). Thus, if the table "was slanting more" gravity would pull the book down easier (052), which is something that doesn't happen in the depicted instance of the card because "gravity actually keeps pulling it" and as a result it keeps it stationary (054).

050 **An** we lift the table up a little bit from one of the sides .. the book does not slide down .. do you think there is a force keeping it there .. /.. umm ..4.. it depends .. 'cos if it was a bit more steep gravity would pull it down .. but as it is not on a very big slant gravity helps it stay ..
051 **Int** what do you mean by .. slant .. /
052 **An** well .. if it was slanting more.. gravity would pull it down.. because it would move more easy .. it would be more steep like that .. [demonstrating it with his hand]
053 **Int** yeah .. I see ..
054 **An** but it is staying there .. it doesn't go down .. so gravity actually keeps pulling it .. to keep it there..

He goes on by referring to his conception of "resistance" again (cf. previous card) and a notion of "slight grip" (056), which he seems to view as a characteristic of the bodies when he says that if we put a block of ice, with the same dimensions of the book, on the table it would "slide down" because "it is absolutely slippery" (058) or because "there is not much grip on it" (059). He appears to be thinking of this "grip" as a "kind of pulling force" which seems to be strongly related to gravity or as he puts it "it kind of goes with gravity" (061).

056	**An**	er.. no apart from the table again .. which is the resistance and .. also a slight grip .. a slight grip there..	
057	**Int**	do you think .. that slight grip .. as you say helps the book stay there.. /	[pointing at the top of the table]
058	**An**	well .. it does 'cos if there wasn't any grip that would obviously slide down 'cos it's on a slant .. say .. if you put some ice there .. that is absolutely **slippery** and it would just slide down straight away.. wouldn't it .. \	
058.5	**Int**	**>>** umm hmm ..	
059	**An**	.. say if there was some ice or something like a block .. same size of the book same shape.. it would slide down .. 'cos there is not much grip on it ..	
060	**Int**	do you think that.. the grip.. is a force then.. /	
061	**An**	umm.. 4.. it's a kind of pulling force down with.. it's the same kind of.. well not actually the same but.. it kind of goes with gravity ..	

(**Pa**) appears to be considering gravity as a force which is keeping the book in its place or in fact "edging it so it can't move" (074). Thus, the book appears to be as if it is "stuck to the table" (076) due to the force of it "coming onto the table" (078), by which he probably means the force of gravity, since he attempts to give an explanation on what he said in the previous utterance. He mentions that if the table is lifted a bit higher that force "will weaken" and the book will start sliding (080), which he claims to be his theory (082).

074	**Pa**	er ..6.. well maybe that force coming down .. holding the book down .. maybe .. but there'll be gravity sort of thing.. like keeping the book there .. edging it so it can't move ..	
075	**Int**	umm hmm ...	
076	**Pa**	so .. I think there .. there's a force .. there.. just you know.. keeping the book from going down.. and it's just like stuck to the table ..	[pointing downwards, under the book]
077	**Int**	what do you mean when you say it's like stuck to the table .. /	
078	**Pa**	like .. with the force .. the force of the book coming onto the table like .. then I think it's like stuck down with that force ..	
079	**Int**	umm hmm..	
080	**Pa**	so it's not going to move .. unless you lift the table a bit more .. then the force will just weaken and it'll start sliding down..	
081	**Int**	yes .. I see..	
082	**Pa**	so ..4.. it's my theory ..!!	

There is an interesting case of a child (**Ph**) who, quite surprisingly, seems to analyse the force of gravity in two components, one pulling the book downwards to the ground and one pulling it along the surface of the table (084). Thus, he suggests that if the table is lifted a bit higher, then the component of gravity pulling the book along the surface of the table "would get less" (084) or the vertical component of gravity would get stronger (088) and as a result the book would slide down. He also considers that if someone pushed the book it would start sliding, because as he claims, "it's just needing a start" (090 & 092).

084	**Ph**	we lift the table up a little bit from one of the sides.. the book does not slide down.. do you think there's a force keeping it there.. ...*(laugh)*... well there's gravity trying to pull it down that way ... that's towards the ground .. but there's also .. there's more gravity pulling it down that way there's more ... more.. if you lift the table a bit more up then gravity would get a bit more like this .. 'cos it'd slide down even more.. and gravity would get less here..	[pointing on the inclined surface of the table] [he represents the table with his hand] [pointing on the inclined surface of the table again]
085	**Int**	yeah .. but the book does not slide down ..	
086	**Ph**	doesn't slide... the way it doesn't slide ... 'cos it's more .. there's more gravity force there than the gravity force there ..	[pointing downwards first and then at the surface of the incline d table]
087	**Int**	all right..	
088	**Ph**	.. it's pulling down under the table more ... it's not enough to take the weight this way ..	[pointing along the inclined surface of the table]
089	**Int**	umm hmm..	
090	**Ph**	if somebody ... if somebody would have given it a push then it would have gone..	
091	**Int**	what do you mean .. ? .. it would have gone ..	
092	**Ph**	yeah it's just needing a start ..	

Furthermore, when (**Ph**) is asked to consider if there is any "friction" in the case of the book remaining still on the surface of the table (since he had referred to a notion of "friction" in the previously discussed instances), he suggested that there is "friction" from the book on the table, " 'cos the book is also a bit coming out and it's sticking itself on the table" (094). He goes on to suggest that somehow "friction" and gravity are pulling against the book the first upwards, along the surface of the table and the latter downwards and they both keep the book still (096).

093	**Int**	right .. do you think there is any friction there .. .. as you mentioned before..	
094	**Ph**	umm .. there's friction from the book on the table .. 'cos the book is also a bit coming out and it's sticking itself on the table ..	
095	**Int**	'cos the book .. ? sorry I didn't hear that could you speak a bit louder please ..	
096	**Ph**	yeah .. the book .. there's friction 'cos when the book is on the table .. like the covers cause a bit of friction and the gravity pulling against it is slowing it down .. kind of thing .. now there's friction in between the book there.. 'cos it's trying to pull that way .. and also it's *(gravity)* trying to pull it down .. so there's got to be a slight friction in there ..	[pointing between the surface of the book and the table] [pointing upwards along the surface of the table]

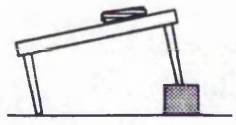
Interview Card	*Groupings of conceptions and alternative conceptions*	*NoR*
	• **The book remains stationary on the table because of the surfaces in contact which are "uneven", "hard", "ripply", or it would slide if they were "slippery" or "shined".**	*3*
	• **"Grip" seems to be a "special effect" of the surfaces which helps the book to remain stationary on the tilted table, but it would slide down if the table was more steep.**	*2*
	• **Gravity "sticks" or "edges" the book on the tilted table**	*3*
	• **Gravity has two components, one vertical and one along the surface of the table which are responsible for the motionless condition or the sliding of the book.**	*1*
	• **There is a "slight friction" between the surfaces of the table and the book which keeps it still.**	*1*

Table 4.1.3: A synopsis of the groupings of conceptions and alternative conceptions from the analysis of the "book on the tilted table" instance with respective numbers of children's responses (*NoR*).

4.1.d. The card with 'the slow-down of the bicycle' instance.

*Three children (**Ph, Da, And**) appear to be considering gravity, or the weight of the person and the weight of the bike, as the main reason for the deceleration of the bicycle. Additionally two of these children (**Da, And**) seem to recognise the role of the wind as another reason for retarding the motion of the bike.*

(**Ph**) seems to indicate that initially there was a push from the person when she was pedalling but this push has now stopped and that together with gravity will eventually slow down the rider and the bike (041). He repeats his view in (044), he suggests that more forces are needed for the bike to move forward (046) and he concludes that "it's got to stop somewhere" (048).

041	**Ph**	well .. there was the push when he was pedalling or she was pedalling and that has given him or her a push and the push is still going and he will eventually slow down .. because the force will not last for ever.. and it's gravity which also slows him down so eventually the rider is just stuck with the bike..
041.5	**Int**	**>>**..yeah..
042	**Ph**	and if he'd stand still .. without riding.. say backwards and forth he'll fall off ..
043	**Int**	why do you think that the pushing you mentioned won't last for ever..
044	**Ph**	'cos it is gravity which will slow it down and decrease it .. and there is nothing to make it go forward any more ..
045	**Int**	all right ..
046	**Ph**	it needs more forces to make it go forward..
047	**Int**	so .. is it gravity that slows it down ..
048	**Ph**	gravity and the fact that there are no more forces making it go forward ... just going there .. it's got to stop somewhere ..

(**And**) also seems to recognise the role of the wind as a hindrance in the movement of the bike, which slows it down (012).

012	**And**	yeah the wind pushing against .. er.. if you 're going pretty fast the wind is kind pushing against you and it slows you down ..

He discusses it further by suggesting that the body weight of the rider is pushing the bike down on the tyres (020) or the ground (022) and "that's even more obvious that gravity will stop it somewhere" (022). Hence he also appears to consider gravity as a cause for the slow down of the bike.

019	**Int**	umm hmm .. is there anything else you want to add on this one..
020	**And**	emm ..4.. your force is pushing even more down on the tyres .. 'cos it quite stops you roll ..
021	**Int**	what do you mean when you say your force ..
022	**And**	well.. your force .. your body weight is pushing down onto the ground.. and that's even more obvious that gravity will stop it somewhere ..

Four children (**Pa, Is, Jo, An**) appear to be ascribing the deceleration of the bike to the loss of power or to the absence of a force pushing the bike in the direction of its movement. Two of them (**Jo, An**) seem to be considering some additional "help" from the "gripping" of the wheels on the ground.

(**Pa**) appears to be thinking of the wind or air as an aid for the movement of the bike, which he refers to as "natural power" (020), but he ascribes the deceleration of the bike to the absence of a force "going on the bike, to move" it (022).

020 **Pa** well there is like ... just like the wind power .. or air.. that is making it go.. so the only power there is .. it's like **natural** power..
021 **Int** yeah .. but why does it slow down then ..
022 **Pa** because there's no pedalling so .. and.. if you're going down a street .. a road.. then you just like.. gradually you will stop because there's no force going on the bike ... to move ..

Later on, he attributes the movement of the bike to an aptitude of the tyres, which are going round all the time (026), but he seems to remain stable in his view that the bicycle slows down because "there is not enough power in it" (028).

025 **Int** what happens with the tyres ..
026 **Pa** they keep going round so.. and that's how the bike moves.. because the tyres are moving all the time .. so the bike moves..
027 **Int** umm hmm ..
028 **Pa** when they slow down it's ... it stops going on because.. there's not enough power in it ..

(**Is**) indicates that the bike will slow down because there is no pushing or pulling force (110 & 112). The contact of the wheels and the ground doesn't seem to play any role to her reasoning, thus she repeats her view, in a rather straightforward way, that the bike will slow down because nobody is pedalling any more (114).

109 **Int** when you ride your bike.. and you stop pedalling .. you do not use the brakes .. but you slow down and eventually you stop.. any idea why that can happen ..
110 **Is** 'cos there's no force there ..
111 **Int** yeah.. what do you mean ..
112 **Is** no force .. pushing or pulling ..
113 **Int** do you think that the wheels that are touching the ground have anything got to do with it ..
114 **Is** you'll slow down 'cos you are not pedalling .. that's what I think ..

(**An**) appears to be considering the pulling force of gravity and a notion of "resistance" from the ground (008) and he also suggests that the bike is decelerating because "there isn't enough power to keep it going" (010). He indicates that there is a

grip at the touching points of the tyres and the ground and that grip slows down the bike (012), but he seems to consider that as the same thing with his notion of "resistance force" (014).

006	**An**	no brakes .. no pedalling .. slowing down .. is there a force on the bike.. .. yes there is ..	
007	**Int**	what sort of force do you think that it is ..	
008	**An**	a resistance force from the ground and a pulling force with gravity..	
009	**Int**	umm hmm .. what do you think makes the bike slow down and eventually stop ..	
010	**An**	well .. without the brakes .. there isn't just enough power to keep it going ..	
011	**Int**	yeah.. do you think there are any forces at the touching points of the tyres and the ground ..	
012	**An**	yeah .. because when the tyres touch the ground .. they grip.. and that grip slows down the bike ..	
013	**Int**	umm hmm .. is that a different force then ..	
014	**An**	umm .. not really .. 'cos it's still the same resistance force .. and gravity pulling it down .. which was there as well. ..	

*Two children (**Ha, Ia**) appear to be considering the existence of "imaginary forces" exerted on the bike pushing to the right or pulling it to the left and, as a result, they slow it down.*

(**Ha**) appears to be sensing a pulling force from the left exerted on the bike, in a rather metaphysical way, since she says that the force "should be" there (080) and that she doesn't know "where it comes from", but she "just" knows that it must be there (088). She suggests that the bike needs that "pulling force" to hold it back and slow it down (080), together with the fact that "nobody is pedalling or pushing or anything" (082). She also thinks that a rough surface of the road would help that "pulling force" and it "would slow down the bike easier" (086).

080	**Ha**	well there should be a pulling force here .. at the back of the bike.. 'cos if it's slowing down.. and there's no pedalling... then.. you see.. it needs that pulling force there .. to hold it back..	
081	**Int**	I see.. is that why it slows down ..	
082	**Ha**	yeah that.. and because there's nobody.. nobody is pedalling or pushing or anything.. and it's not going very fast either..	
083	**Int**	do you think there are any forces there at the touching points of the wheels and the ground..	
084	**Ha**	well ..6.. the pulling force is pulling the bike .. that way ... which is stopping it from going.. slowing it down and eventually stop it..	[pointing to the right]
085	**Int**	umm hmm..	
086	**Ha**	and .. if the surface of the road is say.. rough.. it .. the bike.. would slow down easier.. so I think.. I think the rough surface is helping that . the pulling force.	
087	**Int**	where do you think this pulling force is coming from ..	
088	**Ha**	er ..4.. it is there.. it must be there.. it slows it down .. but .. I can't really say where it is coming from .. umm.. I just know it must be there .. *(laugh)*	

(**Ia**), in an attempt to explain the deceleration of the bicycle, appears to be using a combination of an "imaginary force" pushing against the direction of the motion of the bicycle (139) and a notion of "grip" on the tyres due to their roughness and their contact with the ground (137 & 138). He appears to believe that the grip is a force which is pushing upwards on the tyres and the "imaginary force" is pushing from the right (144). Thus, he suggests that "the grips are getting into the road" and they are pushing the bike up, slowing it down, and the "imaginary force" is pushing from the left slowing it down "even more". Eventually they are putting the bike to a halt (148).

137	**Ia**	the roughness on the tyres	
137.5	**Int**	**>>** .. the roughness on the tyres ..	
138	**Ia**	yeah.. it's got a grip .. and.. it could make it slower 'cos it's touching the floor and that's making it slower ..	
139	**Int**	yeah .. umm hmm .. and is that why it is slowing down and eventually it is going to stop ..	[pointing to the right]
140	**Ia**	yeah .. and also the forces pushing that way ..	
141	**Int**	umm is that a different force ..	
142	**Ia**	ah .. yeah .. what force ..	
143	**Int**	the one that is pushing against the direction of the movement of the bike ..	
144	**Ia**	ah .. yeah it **is** different .. 'cos that is pushing it up and that is pushing it that way ..4.. it is a different force ..	[force from the tyres] [pointing to the right]
145	**Int**	yes .. and do you mean it is a different force from that gripping you said on the touching surface of the tyres and the ground ..	
146	**Ia**	yeah ..	
147	**Int**	umm hmm ..	
148	**Ia**	.. and .. 'cos that's pushing it up .. and it's slowing .. er.. on the road .. and it's .. the grips are getting into the road and pushing it *(bike)* up and eventually slowing .. and that's pushing that way and it's slowing even more ... the bike and the person get into a halt .. and that's it ..	[pointing to the right]

(**And**) indicates that because the tyres of the bike are touching the ground they will slow it down "all the time" (016). He appears to be influenced from a video clip he has seen where he compares the motion of an aeroplane in the air with the motion of the bike on the ground and he somehow seems to infer that the contact of the surfaces will slow it down (018).

015	**Int**	do you think there are any forces at the points where the wheels are touching the ground ..
016	**And**	yeah ... yeah.. what it could be is .. 'cos in a clip I've seen.. it says when you're in the air in an aeroplane.. it wouldn't happen so much .. because you are not touching the ground and you just kind of float in the air.. but when you are on the bike .. you 're actually touching the ground .. so it slows you down all the time ..
017	**Int**	do you mean the touching of the tyres on the ground ..
018	**And**	yeah .. that slows you down ...

Only one child (**Ph**) appears to be considering a "slight bit of friction" at the touching points of the tyres and the ground (050). He seems to suggest that the tyres are

"catching" a bit of friction because they are touching the ground (050) and since they are also spinning round they get "hottish" (052) as they rub up (054).

049 **Int** do you think there are any forces under the wheels of the bike ... as they are turning round ..

050 **Ph** when they are turning round there's a slight bit of friction .. ish .. like if it 's going round and it's touching the ground .. I think it's catching friction on the tyres ..

051 **Int** yeah .. in what way do you think friction will be there ..

052 **Ph** well it's just touching the ground it won't be friction .. like a burst of tyre.. you see.. there'll just be friction.. by the touching of the ground .. spinning round makes all wheels hottish .. I suppose ..

053 **Int** hottish ..

054 **Ph** yeah rub them up ...

Interview Card	*Groupings of conceptions and alternative conceptions*	*NoR*
	• **Gravity seems to be the main reason for the deceleration of the bike**	*3*
	• **the wind can be additional reason for retarding the motion of the bike.**	*2*
	• **The bike slows down because there is not enough power to keep it going or there is no more pushing force**	*4*
	• **the gripping of the wheels on the ground seems to "help" as well.**	*2*
	• **There are "imaginary forces" pushing or pulling the bike in the opposite direction of its movement and they seem to be slowing it down.**	*2*
	• **The "touching" of the tyres on the ground slows the bike down.**	*1*
	• **There seems to be a "slight bit of friction" at the touching points of the tyres and the ground.**	*1*

Table 4.1.4: A synopsis of the groupings of conceptions and alternative conceptions from the analysis of the "slow-down of the bike" instance with respective numbers of children's responses (*NoR*).

4.1.e. The card with 'the parachute' instance

All of the children recognise the force of gravity pulling the box of medicines and the parachute down, towards the earth. They appear to be considering a force pushing upwards slowing down the descent of the parachute, or they seem to be sensing that the air has certain properties which somehow it affect the phenomenon.

*Five children (**Ia, Ha, Da, Is, An**) appear to be sensing a force from the air pushing the parachute upwards, retarding its downfall and somehow opposing or resisting the force of gravity which is pulling it downwards.*

(**Ia**) appears to be considering that air makes the parachute "go upper" (162) and he suggests that "if there weren't any air it wouldn't be slowing down" (164). Thus, according to his view, air is getting inside the parachute pushing it up, slowing it down and if this wasn't happening it would go down "really fast" (170).

162 **Ia** because air makes it go upper /.. gravity isn't there .. /
163 **Int** yeah.. is that what happens.. /
164 **Ia** ..6.. well if there weren't any air it wouldn't be slowing down *(laugh)*.. \ ..
165 **Int** sorry .. I didn't get that one..
166 **Ia** well ..4.. the air is ..8..
167 **Int** umm.. is there any air getting inside the parachute .. /
168 **Ia** yeah ..
169 **Int** what do you think is happening then .. /
170 **Ia** it's like the air pushing it up .. 'cos that *(the box)* is pushing it down *(the parachute)* .. and it's getting rushing .. that is if .. there weren't anything.. you know.. like force pushing it up .. that would go **really** fast down ..

(**Is**) seems to be suggesting that the parachute goes down slowly because it "catches the air". She senses that there will be a pushing force (094), but appears to be reluctant in identifying the source of this pushing force. Finally, she makes a rather uncertain suggestion that "it could be the force of the air", somehow pushing the parachute up (100).

089 **Int** what happens with the parachute why does it go down slowly .. .. and it does not go fast .. remember it was thrown from an aeroplane ..
090 **Is** because the parachute catches the air .. or something.. *(laugh)*
091 **Int** yeah ..
092 **Is** .. and it stops the box from going down fast..
093 **Int** umm hmm .. anything else that you would like to add here.. '
094 **Is** well there'll be a pushing force ..
095 **Int** where from .. /
096 **Is** umm ..8.. dunno.. er.. air maybe .. \
097 **Int** a pushing force .. you say.. where in which direction can you show me ..
098 **Is** there .. [pointing under the parachute]
099 **Int** yeah .. what force would that be .. '
100 **Is** it could be the force of air.. sort of pushing it up ..

(**An**) appears to be recognising the force of gravity (018) and notion of "a resistance force from the air" that is trapped inside the parachute. He means, quite possibly, that the "resistance force" from the air is actually "resisting" the force of gravity, pulling the parachute downwards and "that's why it goes down slowly" (020).

018 **An** a box full of food and medicines was dropped with a parachute from an aeroplane .. it goes down slowly.. do you think there are any forces here.. .. oh .. 4.. there's the weight force pulling it down .. that's gravity again ..
019 **Int** do you mean the weight of the box .. '
020 **An** yeah .. and the parachute .. and there's a resistance force from the air when the parachute is coming down .. and it traps the air .. which resists it .. that's why it goes down slowly ..

*Three more children (**And, Jo, Ph**) appear to be thinking in similar terms referring to the air pushing the parachute upwards, slowing it down, but additionally, they seem to be explaining this effect of the air on the parachute in a rather graphic way, using analogical reasoning.*

(**And**) pictures the parachute as a "massive wide space" which is "getting air into it" and that's why it will stay up longer (094). Thus, he suggests that the air is pushing "up onto the top of the parachute" (098) and it is spread all over it, but it appears to him that if it had a big hole in it would come down faster (100).

094	**And**	yeah .. well .. the parachute is ..4.. getting air into it so it might .. it's gonna .. it's a massive wide space so .. it'd stay up a bit longer .. than as if just jumping out of an aeroplane without any parachute ..
095	**Int**	umm hmm .. what do you think is pulling the box down ..
096	**And**	well .. it's gravity .. that's another force here ..
097	**Int**	yeah.. why do you think the box goes down slowly ..
098	**And**	because all the air is pushing up onto the top of the parachute ..
099	**Int**	umm hmm ...
100	**And**	and it's .. it's spread all over the parachute .. as it comes down .. well it might.. say if it had a big hole in it.. in the parachute .. it'd come down really quickly ..

(**Jo**) recognises the force of gravity pulling down both the parachute and the box (061), but she describes the parachute as if it has "a roof", which is filled up with air pushing in the opposite direction of its descent, slowing it down (063). In this sense, she suggests that the air is holding the parachute up longer (065), but she also appears to be considering the existence of a force from the strings of the parachute which are holding the box in its place (067).

061	**Jo**	and the box takes down the parachute with it .. gravity pulls them down together ..
062	**Int**	umm hmm .. and they both go down slowly .. why do you think that happens..
063	**Jo**	well .. as the parachute is coming down .. the air goes under what .. say the roof of it.. and stays there.. so.. it will be going the opposite way of the parachute .. it will fill the parachute and eventually slow it down ..
064	**Int**	yeah ..
065	**Jo**	so.. air is actually holding it up longer .. otherwise it would go down.. zumm.. *(laugh)*..
066	**Int**	*(laugh)* .. yeah .. I see.. any other forces here ..
067	**Jo**	umm .. yeah the parachute is holding the box up .. by some sort of strings .. or whatever is holding it there ..

(**Ph**) seems to be viewing the air "which is supporting the parachute" and the strings that "hold it up" as a system for retarding the descent of the parachute, which is "acting as brakes" (026). Rather surprisingly, he also refers to a notion of "tension" on the strings of the parachute which he possibly views as a force (028 & 031).

026	**Ph**	a box full of food and medicines was dropped with a parachute from an aeroplane .. it goes down slowly ..do you think there are any forces here .. / ..4.. yeah.. there's gravity pulling the .. box down .. and there's the air which is supporting the parachute stopping it from falling too quickly .. and if they *(strings)* hold it up.. they not.. hold it.. it won't move fast .. but slowing it down .. like acting .. acting as brakes..	
027	**Int**	oh .. I see .. you feel that it acts as brakes anything else .. /	
028	**Ph**	oh .. well passed the brakes... there's a tension on these lines.. you've got the brakes tension on the lines and you've got the gravity.. \ .. that's about it.. \	
029	**Int**	sorry I didn't get the last bit .. could you please say that again .. it's getting a little noisy here..	[there's some noise from some people going out of the classroom next door]
030	**Ph**	yeah .. you've got the parachute there which is the brakes .. you've got the tension here on the:: ..	
030.5	**Int**	**>>** strings or ropes...	
031	**Ph**	.. yeah .. and you've got gravity from the box full of medicines ... that's about all the forces you've got here I reckon ..***.. \	

Finally, there is a case of a child (**Pa**) who seems to be a bit confused and somehow he views a force "from ground which is giving the air", the air as a force "which is coming up into the parachute" and a force coming down from the top pulling the parachute and the box downwards (047), which he thinks is gravity (049).

044	**Int**	so .. how many forces are there .. /
045	**Pa**	there's three .. I'd think of .. \
046	**Int**	three you say .. can you name them again please .. /
047	**Pa**	well there's the one from the ground which is giving the air .. the air which is coming up into the parachute .. and there's the force coming down .. and there's like .. the food that's like a force coming down .. 'cos it's heavy so.. that's edging it down all the time..
048	**Int**	yeah .. I see ..
049	**Pa**	I think gra .. gravity is the last one .. I think so .. gravity is coming down from the top of it .. and pulling it down.. \
050	**Int**	do you mean the box or the parachute .. /
051	**Pa**	both I guess ..

Interview Card	*Groupings of conceptions and alternative conceptions*	*NoR*
	• **A force from the air is held inside the parachute pushing it upwards opposing the force of gravity pulling it downwards**	*5*
	• **Air is getting inside the parachute which is like a "massive wide space" or it looks as if it has "a roof" and slows it down or its "strings" look like brakes that retard its descent.**	*3*
	• **There is a force from the ground which "is giving the air" and another force which is coming up into the parachute slowing it down**	*1*

Table 4.1.5: A synopsis of the groupings of conceptions and alternative conceptions from the analysis of the "parachute" instance with respective numbers of children's responses (*NoR*).

4.1.f. The card with 'the person on the skateboard' instance

*Four children (**Ia, Ph, Pa, Ha**) appear to be considering a metaphysical notion of an "imaginary force" from the right, in the opposite direction of the motion of the skateboard, slowing it down. They indicate that this force is exerted on the person, the skateboard or even on the wheels, but they do not seem to be able to identify its nature or its source.*

(**Ph**) appears to be sensing that there is a force in the opposite direction of the motion of the skateboard (110 & 112) and he suggests that it has to be pushing the skateboard in that direction, otherwise it would "keep going" (114). Thus, he attempts to explain the deceleration of the skateboard in a commonsensical way, by pointing out that there "has to be something" pushing it from the right (116). He appears to be conceiving an analogical relation between that "imaginary force" and the weight of the person and the skateboard (116). Thus, the more weight is put on the skateboard, the more "force" will be pushing it to the left.

110	**Ph**	and it's also the fact that... it's got to go that way so it'd stop it.. it's going to have to stop somewhere.. so it might.. so.. oh God ... .. **gra**vity is pulling it down there and also there's a force pushing it that way ..	[pointing to the right] [not really pointing somewhere]
111	**Int**	pushing it ... which way..	
112	**Ph**	pushing it against it	
113	**Int**	against it .. yeah ..	
114	**Ph**	'cos there is nothing pushing it that way .. so there's got to be a force pushing it that way.. or it would just keep going and going and going until gravity would stop it somewhere..	[pointing to the right and then to the left]
115	**Int**	all right .. any idea what sort of force is pushing that way .. .. against the movement of the skateboard ..	[pointing to the left]
116	**Ph**	well there'll have to be ... if there were nothing it would keep going that way.. but like ... there has to be something pushing it that way .. but even the weight of the person is going to pull it *(the skateboard)* back .. there 's more ... like the more weight you put on there it would slow down even more.. we are having gravity right there ... and the more force we are getting from there ..	[pointing to the right] [pointing to the left] [pointing to the left]

(**Pa**) appears to be considering a force which makes the skateboard move (092) and another force from the right (094) which looks as if it is "hitting" the skateboard, slowing it down or "pushing it off" in a way (096).

092	**Pa**	rolling with the skateboard .. no pushing .. slowing down .. do you think there are any forces here .. .. well there's the force which is making it move .. to start with ..	
093	**Int**	umm hmm ...	
094	**Pa**	then there'll be a force coming from that side .. I think ..	[from the right]

095	**Int**	do you mean from the opposite side .. '	
096	**Pa**	yeah .. then I think .. **that** force is like hitting the skateboard when.. like.. so it'll slow down .. but with the other force it'll like hit it but when the other force is still there .. see .. the force we have here it's like .. just push off .. you know ..	

Later on, he appears to be indicating the existence of the same two forces on the wheels of the skateboard (100). He goes on to suggest that the force coming from the right is like "hitting the wheels", slowing them down and eventually the skateboard will stop "with the force on them" (102).

099	**Int**	do you think there are any forces on the wheels of the skateboard.. /	
100	**Pa**	yeah .. to make it go.. and there'll be a force coming that way again 'cos that's how you make it stop ... so I think it's like a force coming from each side again..	[from the right]
101	**Int**	yeah .. can you tell me how do you think that the force that comes from that way .. as you say.. will slow down the wheels .. '	[from the right]
102	**Pa**	yeah .. it's like hitting .. see the wheels are going round and round and when you hit .. like hit the wheels and it'll slow... keep going round but slowly.. it *(the skateboard)* will stop with the force on them .. ' ..	

Then he is asked to explain what he means when he says that the force from the right "hits the wheels". He claims that the force looks as if "it goes on the wheels" and then "they slowly go round" till the skateboard stops moving (106). He does not seem to know where this force comes from (110 & 114), although for a moment he thinks that it could be the wind (112).

106	**Pa**	hits them .. yeah .. like goes onto the wheels and they slowly go round and gradually it'll stop .. *(the skateboard)*	
107	**Int**	oh .. I see .. and where do you think that this force comes from..	
108	**Pa**	umm .. the force .. it's coming from in front of there .. and it's like ..4..	[pointing to the right]
109	**Int**	what is in front of there .. '	
110	**Pa**	umm.. I don't ... I don't know where the force is coming from ..	
111	**Int**	all right I see ..	
112	**Pa**	it could be the wind force or something ..	
113	**Int**	yeah ..	
114	**Pa**	or ..6.. I am not really sure where it's coming from.. the force .. *(cough)*..	

(**Ha**) appears to be thinking that the skateboard is decelerating because there is no more "pushing" (052), while she also indicates that there "must be a pulling force" from right, which somehow hinders its motion (054), but she seems uncertain about the source or the nature of this force (058).

051	**Int**	yeah it is now moving slowly .. and it will gradually stop ... why do you think that happens ..	
052	**Ha**	er ..4.. 'cos there is no pushing .. no pushing ... that'll slow it down ..	
053	**Int**	yeah ... any other forces here ..	
054	**Ha**	yeah ... there must be a pulling force from there ..	[from the right]

055 **Int** do you mean from the right .. /
056 **Ha** yeah ... it's stopping it from going...
057 **Int** do you know where this pulling force comes from .. /
058 **Ha** no .. I can't think of that ...

Three children (**Ha, An, Jo**) appear to be considering a notion of "gripping" of the wheels of the skateboard on the surface of the ground and they point out that it could be a reason for the deceleration of the skateboard.

(**Ha**) suggests that if the surface of the ground was rough or "rumply" then the skateboard "wouldn't go without being pushed" and it would slow down more easily (060). She points out that "it would take longer" for the skateboard to stop on a flat surface because the wheels "wouldn't grip as much" (062), but as she mentions, she "just knows" why that happens, probably implying that she has observed it (064).

059 **Int** all right ... do you think there are any forces there ... at the points that the wheels of the skateboard are touching the ground .. /
060 **Ha** well .. if it was a really rough surface ... a really rumply surface .. then it wouldn't go without being pushed .. and it would slow down .. easily ...
061 **Int** yeah .. I see .. anything else you want to add here .. /
062 **Ha** yeah ... it would take longer .. for it .. to stop on a flat surface ... 'cos the wheels wouldn't grip as much ..
063 **Int** umm hmm .. I see .. why do you think that happens .. /
064 **Ha** er ..4.. I just know .. I've seen it ...

(**An**) appears to be a bit puzzled when he attempts to explain why the skateboard slows down. Thus, he suggests that "it gets heavier" "because of gravity " and since there is no more force pushing it will slow down or "run out of force really" (026). Then he refers to the contact of the wheels with the ground (029) and to a "slight bit of grip" that exists there and prevents the skateboard from sliding "all over the place" (032). Finally, he mentions that this gripping helps a notion of a "resistance" force (028 & 034) which slows down the skateboard.

027 **Int** I see.. why does it slow down then ..
028 **An** because gravity .. and the weight of the skateboard .. it gets heavier .. so without any more force pushing it. .. and with a bit of resistance .. it slows down .. it runs out of force really ..
029 **Int** umm hmm .. do you think there are any forces at the touching points of the wheels of the skateboard and the ground ..
030 **An** umm .. if they weren't touching.. if there weren't any wheels .. say if it didn't have any.. it would still slow down without any force pushing it..
031 **Int** yes .. I understand that .. but in this situation that the skateboard does have wheels on .. what do you think that happens..

032 **An** umm ..4.. well there might be a slight bit of grip.. because .. otherwise if there wasn't any grip.. it would slide abouts all over the place really..
033 **Int** is that another force then .. /
034 **An** umm .. no I don't think so .. I don't think you can call that a force really .. it's just a bit of grip .. it probably helps that resistance force .. that's what I reckon...

*Two children (**Da, And**) seem to be discussing "gravity" or the "weight" of the person and the skateboard as a cause for its deceleration.*

(**Da**) appears to be suggesting that gravity, which is pulling the skateboard down, is the same force that is slowing it down (039). He does not consider any forces at the touching points of the wheels and the ground (041).

039 **Da** .. er.. gravity is like pulling it down so.. which is stopping it ..
040 **Int** umm hmm.. do you think there are any forces at the touching points of the wheels and the ground.. /
041 **Da** no .. I don't think so...

(**And**) refers to the force of gravity (083) and he claims that the weight of the person is pushing the wheels which are touching the ground, exerting "a lot of pressure" on it and that slows down the skateboard (085 & 087).

083 **And** well you are standing on it .. so it's just gravity .. er ..4..
084 **Int** what makes it slow down and stop then .. what do you think ..
085 **And** umm ..4.. well.. it's touching .. the wheels are touching the ground .. and so if it's rolling there.. your.. your .. weight.. is pushing on the wheels so .. it's got to slow.. 'cos .. it might slow .. you'd slow down because it's heavy.. the wheels is like putting a lot of pressure on the ground .. so it might slow down that way .. [pointing at the touching points of the wheels and the ground]
086 **Int** umm hmm .. so do you think that the skateboard slows down because of the pressure of the wheels on the ground .. /
087 **And** yeah .. and your weight ..

*Two children (**Ph, Da**) seem to regard "wind" as a force which slows down the skateboard or pushes it along, depending upon the direction of its blow.*

Thus, (**Ph**) suggests that if the wind is blowing "in the face" of the person, it will slow him/her down, while if the wind is blowing in the opposite direction it will push the skateboard further (129).

126 **Int** all right .. any other forces here..
127 **Ph** umm ..4.. it depends whether it's windy or not /
128 **Int** why do you say so..
129 **Ph** if the wind is blowing in his face.. it'll... say catch him round and slow him down more .. but if it is behind him it's going to push him there and he 'd go a bit further... [pointing behind the person's back]

Similarly, (**Da**) suggests that if "the wind is blowing behind" the person it is going to push him/her along (043), but even in that case, he claims that the skateboard will eventually stop (045). He points out, though, that he cannot explain why this happens (047).

043	**Da**	well it's the wind .. it depends where it is blowing from... if the wind is blowing behind him ... it's like pushing him along.. same with the bike ..
044	**Int**	yeah ..
045	**Da**	.. but I think that eventually it will stop ..
046	**Int**	umm hmm... any idea why that will happen ..
047	**Da**	er.. no I can't really explain this ..

Only one child (**Ph**) appears to be considering a notion of "friction" at the touching points of the wheels and the ground (120), but he seems to be viewing friction as a force "going against the force of gravity" (123). As he suggests, both of these forces slow down the skateboard (125).

119	**Int**	yeah .. O.K. do you think there are any forces at the points where the wheels of the skateboard are touching the ground ..
120	**Ph**	friction again ...
121	**Int**	friction again ... .. you said ..
121.5	**Ph**	>> yeah ...
122	**Int**	.. in what way ..
123	**Ph**	well... there's gravity pulling it down .. and it's trying to go... it's trying to ... it's still going against the force of gravity ... so it's friction on the wheels ...
124	**Int**	umm hmm ... do you think that this is the force that .. slows down the skateboard ..
125	**Ph**	yeah .. the one .. the force of friction .. and .. the fact that gravity is pulling everything down .. ** ..

Interview Card	*Groupings of conceptions and alternative conceptions*	*NoR*
	• **There seem to be "imaginary forces" from the right, pushing against the motion of the skateboard slowing it down**	*4*
	• **The "gripping" between the wheels of the skateboard and the surface of the ground seems to be a reason for its deceleration**	*3*
	• **Gravity seems to be a cause for the deceleration of the skateboard**	*2*
	• **Wind seems to be a cause for the deceleration of the skateboard**	*2*
	• **"Friction" together with gravity seem to slow down the skateboard**	*1*

Table 4.1.6: A synopsis of the groupings of conceptions and alternative conceptions from the analysis of the "person on the skateboard" instance with respective numbers of children's responses (*NoR*).

Discussion

Some children appear to be holding a conception of "grip" which is ascribed to external or internal properties of surfaces that can hold things (book on the tilted table) or slow down their motion (bike, skateboard). Thus, there is a view that "grip" depends on the surfaces in contact. They may have some "grip" if they are "uneven", "hard" or "ripply" and they probably don't have much "grip" when they are "slippery" or "shined". But also, "rubber" can hold things since it has more "grip", or "plastic" may let things "roll down". Some children appear to be holding preconceptions about the role of "roughness" of surfaces in the phenomenon of "grip" by identifying some aspects of their interdependence. They appear to discuss "grip" in a qualitative way thinking in terms of everyday experiences with the nature of materials and their effects on certain phenomena of surfaces in contact. Nevertheless, "grip" is not generally considered to be a force, although it can "hold", "pull" or "push off" things.

Some children appear to be considering that "gravity" may "hold things" since it can "stick" or "edge" them on a surface (e.g. the car on the road, or the book on the titled table). It can even decelerate the movement of a bike because it is "pulling it down", "pressing" or "forcing" its tyres to touch the surface of the ground (same with the skateboard). Perhaps they sense gravity as a necessary condition for the contact of two surfaces, but they do not appear to be thinking of a way to relate that with a notion of "grip", which may affect the motionless condition or the deceleration of moving objects. The latter is usually seen in combination with the "loss of power" or the absence of a "pushing force".

Some children appear to be sensing the existence of "forces" that are pushing or pulling against an intended movement (car being pushed) or the motion of an object (bike or skateboard), in a rather metaphysical way, without being able to describe their nature or origin. Hence, these forces seem to exist and act in certain directions in order to explain phenomena or desired outcomes as they appear in the depicted

instances. It could be claimed that these "imaginary forces" are children's intuition about the existence of a force which opposes the movement of objects or decelerates their motion.

Some children seem to be considering that "the wind" is slowing down objects that move through it (bike, skateboard). In the case of the parachute, the "air" appears to retard its descent, "pushing" it in the opposite direction of the force of gravity. In this respect, "air" or "the wind" appear to be seen as a retarding medium for objects that move through it.

Only one child (**Ph**) mentions the word "friction". He appears to be suggesting that there is a "slight friction" between the surfaces in contact that holds things together or slows down the motion of objects. He appears to be considering "friction" in terms of a pushing or pulling force closely associated with what other children describe as "grip" and its effects between surfaces in contact. Quite surprisingly, he also refers to two equal forces, gravity and a force from the table, which keep the book in its place (book on the table instance). He also appears to have developed an approach of two components of weight, one pushing downwards and one along the surface of the table, which seem to be responsible for the motionless condition of the book or for its sliding down the tabletop (book on the tilted table instance). These conceptions about force, gravity and frictional phenomena appear to be elaborated and rather advanced and indicate a child with a special interest in science. Furthermore, at the end of the interview, he mentioned that he had read a book about "friction and stuff" and that's why he "knew about such things". However, he was not heard to mention anything about friction during the teaching intervention that followed, or at least the researcher didn't realise such a thing.

4.2.0. The teaching intervention in England

The teaching intervention in England was carried out in a Year 6 class, at a primary school, in Nottinghamshire. It was a series of three teaching sessions which had been planned by the researcher in collaboration with the teacher, but were mainly taught by the latter. At certain moments the researcher acted as an assistant teacher helping the children with their investigations. For most of the time though, the researcher was sitting in a corner of the classroom and was observing the sessions. There were two tape recorders in different corners of the classroom, which were used to record most parts of the classroom debate. Some pieces of children's authentic verbiage are presented within speech marks in the teaching sessions that follow.

At the time of this teaching intervention the children were exploring "forces and motion" and they had done several investigations. They had investigated the movement of "buggies", which were pushed or pulled along the floor or at different slopes, the resistance of air or water by dropping various pieces of paper of different shapes, or by observing various balls of plasticine descending inside a container filled with water. They had also investigated pressure through a rather funny, but most interesting, problem solving activity where they mainly had to answer the question *"Why doesn't the fakir hurt much when he sits on his bed which is full of nails? Is it only kind of "magic" or not?"*. Generally, they seemed to enjoy science investigations and most of them seemed to have an interest in exploring "forces and motion".

Before the three sessions of the teaching intervention are described and presented, there is a reference and a short analysis of the National Curriculum (DES, 1991) on the concept of friction, which is followed by a description of the specific classroom setting of this study.

4.2.1. Referring to the National Curriculum

In the National Curriculum for England and Wales (DES, 1991) the Attainment Target 4 is on "Physical Processes". In the Programme of Study, the third strand is entitled "forces and their effects". There we can read that pupils, at this stage of schooling (Key Stage 2, levels 3-5), should:

> ... explore different types of forces including gravity and use measurements to compare their effects in, for example, *moving things and bridge building*. They should investigate the strength of a simple structure. They should be introduced to the idea that forces act in opposition to each other, that one force may be bigger than another, or be equal to it, and that the relative sizes and directions of the forces can affect the movement of an object. They should investigate the factors involved in floating and sinking. **They should explore friction**[1] and investigate the ways in which the speed of a moving object can be changed by the application of forces. This work should be set in everyday situations, for example, *road safety, transport (including cycling and sailing), balancing systems and hydraulic mechanisms in model making* (p. 44)

Thus, pupils should, amongst other things related to forces and movement, "explore friction", but it is not specified in what way and how this could be achieved. There are many different ways to explore friction and there are many different approximations to frictional phenomena, as there are three kinds of friction, namely static, kinetic or sliding and rolling friction (cf. Chapter 2 & Appendix I). It is, therefore, a challenge for the teacher and the learners to organise investigative activities which could promote fruitful and meaningful learning experiences in order to explore certain frictional phenomena and their nature.

In the NCC consultation report (1991), in the Statements of Attainment for Level 5, in (**e**) we can read that pupils *should*:

- know that gravitational forces and friction forces affect the movement of an object (p. 45).

In the Examples which are next to the Statements of Attainment we read that pupils *could*:

- use diagrams to show how the forces of gravity and friction act when they cycle on different gradients and at different speeds (p.45).

[1] The emphasis in bold characters is added.

Knowledge about how gravitational forces and friction forces affect the movement of an object may be achieved or constructed through investigative work and classroom experimentation. Moreover, learners would probably have to go through some phases and degrees of conceptual change. It would be more difficult though, to show how friction acts when a person is cycling on different gradients and speeds. Rolling friction is a difficult concept (cf. Appendix I) and, in my opinion, it cannot be easily taught or explained at Key Stage 2. Nevertheless, some questions could be answered within the "surface roughness" approximation of frictional phenomena, which is adopted here as an explanatory framework.

In the most recent version of the National Curriculum for England and Wales (DES, 1995), friction appears to be a "type of force" and it is stated that pupils should be taught:

> (c) about friction, including air resistance, as a force which slows down moving objects (p. 12).

Thus, air resistance appears to be considered as a frictional phenomenon suitable to be taught and investigated in primary school. A more general, leading conception about friction appears be that of a "type of force which slows down moving objects", but let us not forget that friction may also "keep things stationary", and that can be equally important in many everyday situations (cf. § 2.5.). The latter is not stressed in the preceding phrase, unless it is included in what should be taught "about friction".

On the other hand, there seems to be some emphasis in the role of air resistance in the motion of objects. Hence, in Key Stage 3 pupils should be taught:

> (e) ways in which frictional forces, including air resistance, affect motion, *e.g. the effect of a descending parachute, the effect of friction between a tyre and a road* (DES, 1995, p. 21).

Thus, rolling friction and relative frictional effects in the interface of "a tyre and a road" appear to be considered as a more advanced phenomenon to be investigated, since it is proposed to be discussed in Key Stage 3 and not in Key Stage 2 (DES, 1995). Nevertheless, in Level 4, which most of the primary school children should have reached by the end of Year 6, pupils should be able to:

> ... make generalisations about physical phenomena, such as motion being affected by forces, including gravitational attraction, magnetic attraction and *friction*, or sounds being heard through a variety of materials (DES, 1995, p. 56, emphasis added).

It is not specified what kind of "generalisations" can be made about a "physical phenomenon" such as "motion being affected" by the "force of friction". But, generalisations like "friction slows things down", "friction wears things away", or "friction creates heat" could be implied.

Within the context of this inquiry, an "exploration of friction" was attempted, through investigative group work and classroom discussion. Some simple experiments were organised during the teaching sessions and several everyday instances concerning frictional phenomena were discussed and analysed. The emphasis was drawn on how new conceptions or new constructions are built, in relation to the prior knowledge of the learners, within the framework of constructivist philosophy. This implies "*direct experience with science as a process of knowledge generation in which prior knowledge is elaborated and changed on the basis of fresh meanings negotiated with peers and teacher*" (Watts, 1994, p. 51) and this is what constitutes a challenge for all the people involved in the educative process.

On the nature of this challenge Watts (1994) comments:

> In the United Kingdom's post-National Curriculum era, the 'coverage' of the content of the statutory 'Programmes of Study' is of immediate importance. The challenge undertaken has been to meet these legal requirements, while at the same time fostering a constructivist approach through active problem solving strategies (p. 51).

There is an attempt to meet this challenge here, throughout the various phases of the teaching intervention that are described later in this chapter.

4.2.2. The classroom setting

The classroom, where Year 6 was situated, was a nice and convenient room of 30 m^2 approximately. There was a big window on the left and there were two doors, one on the left of the room and one at the back of the room (see fig. 4.2.1). A chalkboard

was situated on the wall, in the front part of the classroom. In the right corner, at the back of the room, there was a sink which was used for washing, cleaning, etc.

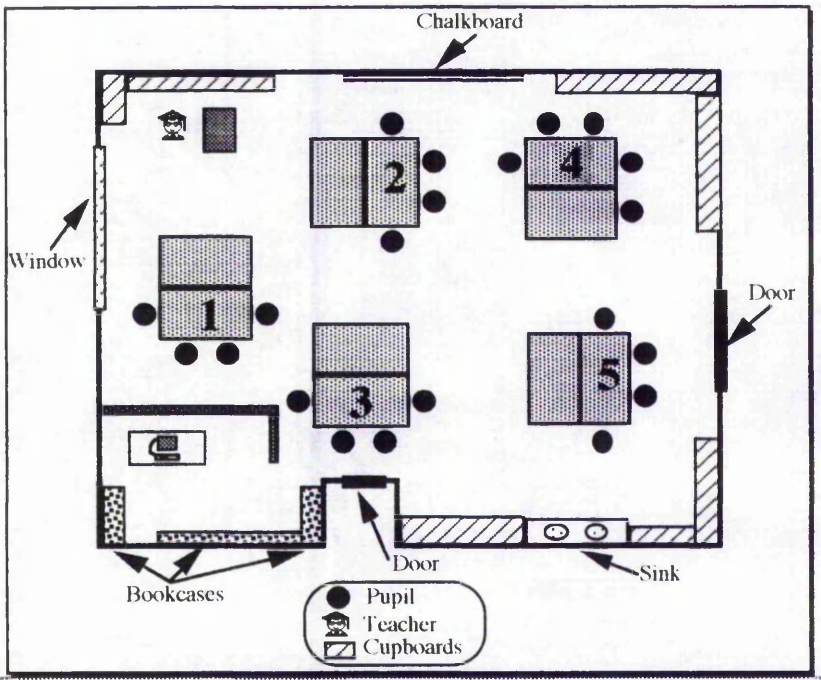


Fig. 4.2.1: This is the Year 6 classroom diagram from the school in England. There are some numbers printed on the desks, ranging from 1 to 5. They represent the equivalent numbers of the children's working groups and they are used as such in the series of teaching sessions that follow. Hence, 'Table No. 5' is actually 'Group 5', or 'the fifth group', with four children, which was situated in the right back corner of the classroom

There were cupboards and bookcases in every corner of the classroom where the children kept their resources, their work and their books and notebooks. The teacher had his own cupboard and a small bookcase next to his desk, where he kept his paperwork, some personal items and books.

In the left corner, at the back of the room, there was a separated area with an ARCHIMEDES computer, where the children could do some project work or they could play some of their favourite computer games during the school breaks. It was also used as a "quiet corner", where the children could do some silent reading by choosing a book from the classroom library which was situated there. Some large pillows were laid on the floor next to the bookcases, where the children could sit and relax while they were reading a book or looking for some information.

The teacher's desk was a rather small table, while the pupils' desks where average-sized tables with plastic laminate on top. The pupils' tables were put together in pairs, one next to the other (cf. fig. 4.2.1). Thus, there was plenty of space on the tables for the children to work conveniently in groups and to perform investigative activities in science or any other subject.

There were twelve (12) boys and (9) girls in the class. At the time that this research project was conducted, the children were working in four groups of four and one group of five, although some changed groups from time to time.

4.2.3. Introductory session

The introductory session was a morning session on a Tuesday in the end of May 1992. It lasted roughly forty-five minutes (45') and the children worked in groups for most of that time. There was some time devoted on a plenary orientation and discussion concerning some explanations in the beginning of the session and some time for reporting and further discussion in the end of this period.

The main focus of the introductory session was a preliminary orientation of the learners and an elicitation of their ideas concerning some frictional phenomena as they were presented within certain "triggering instances" (see Table 4.2.1). Each "triggering instance" consisted of an initial question or a brief description which presented the instance. Another question followed, the same for all of the instances, asking for an explanatory comment. The instances were chosen from everyday life occurrences and they are considered to be familiar to the children who either had such personal experiences in the past (questions for Groups A & E) or they could try them out in class (questions for Groups B, C & D). For example, group A had to deal with the following "triggering instance": *What happens when we try to walk on ice? Why does this happen?*

The session was expected to trigger and elicit some of the children's ideas concerning the specific instances and certain consequences that can be drawn on these, so that the learners would:

- become sensitised to certain phenomena where friction is present in one way or another, by trying to guess what the "triggering instances" have in common
- express and become aware of their ideas concerning certain frictional phenomena, by writing, reporting and discussing their group work with the rest of the class
- develop their communication skills through a whole class discussion in reference to certain "triggering instances" on frictional phenomena, by reflecting and receiving social feedback on their exposed ideas.

At the beginning of this session, the children were told that they were going to investigate a new concept in science. They were not going to be given a name for it and they were not going to be told what it was about. Instead, they were told that it was to be kept a mystery and that they had to guess for themselves what the concept under investigation was. This mystery and guessing about the new concept seemed to capture their curiosity and to stimulate their interest.

Read the following questions carefully. They deal with situations that have something in common. Each group will have to try to answer one question and write down a short paragraph about it. Each will have to choose a representative who will report the group's work to the whole class.

QUESTIONS

Group A	What happens when we try to walk on ice? Why does this happen?
Group B	We gently push a book on the table, it slides for a short distance, it slows down and then it stops. Why does this happen?
Group C	What happens when we try to write with a piece of chalk on glass? Why does this happen?
Group D	What happens when we try to hold a pen and our hands are wet or sweaty? Why does this happen?
Group E	What happens when we ride our bike and suddenly we go over some oil which is spread on the road? Why does this happen?

Table 4.2.1: The leaflet that was distributed to the children during the introductory session

After that, each group was given a leaflet, which is reprinted here in table 4.2.1. Each group had to perform the following tasks:

- tackle and discuss one question respectively in an attempt to give an explanatory answer
- agree on a written version of their answer and choose one of the members of the group to report it to the whole class
- consider and think over the remaining questions that the other groups were working on and try to guess *what* they have in common.

First they were told to read the leaflet briefly. Then the teacher asked if there were any questions. Group C asked if they could take some pieces of chalk and try to write something on the glass of the classroom window and the teacher replied affirmatively, provided that they would not disturb the rest of the class. One member of group D said that she wanted to wet her hands in the sink and then try to write with a pen and see what happens and the teacher encouraged her to do so. One member from group E remembered that he had seen something about bikes slipping on oil and ice in one of the books from the classroom library and he went to look for it while the rest of the group started exchanging ideas and opinions. At that moment, the teacher mentioned that the children could use any of the classroom resources which they thought that would be useful and would help them along their task. Group B cleared up the desks and they started experimenting with books and notebooks pushing them along the table. One of the members of Group A complained that they didn't have anything practical to do, but at the same time, another member of the group mentioned that all of them had slipped on ice and they knew all about it.

By the end of this first round of questions and spontaneous activities which lasted for about ten minutes, the children had returned to their seats and were discussing their experiences. The researcher and the teacher were observing these discussions by moving around the classroom and listening to the children talking to each other.

All of the members of group A accepted the fact that we may all slip on ice because we cannot grip easily and each one expressed his or her own experience. Then the main focus of the discussion was shifted to ways and means that could be used in order not to slip on ice. One pupil said that she wouldn't slip easily if her shoes were made of rubber and had a good grip. Another pupil mentioned that he could take advantage of slipping on the ice if he wore ice skates and he could move a lot faster without falling down. Another pupil commented that this could happen only on a frozen lake and not on a road or on a pavement.

The members of group B agreed that the books and notebooks they experimented with, slowed down and stopped because there was no more force pushing them along and the table was hindering them in a way. One of the pupils in the group mentioned that one of the books that had a "bumpy" cover stopped faster than a notebook with a smoother cover. This, she explained, had to do with the cover of the book because "the smooth one slipped further along". Another pupil observed that in most of the times that he tried, the book stopped just before it reached the end of the table, but he thought that it wasn't relevant to what was going on and "it was a matter of a push really". Another opinion was that gravity pulls the book down and sticks it on the table and that is the reason that the book stops sliding. This was also accepted as a cause by the rest of the group.

Group C was surprised that it wasn't easy at all to write with a piece of chalk on the window glass. One of them said that he thought that chalk could write anywhere, but at the same time another one mentioned that she had difficulties in writing on the desk with a piece of chalk (the desk was covered with plastic laminate). Another pupil mentioned that "the chalk does not leave a line on the glass because it is very smooth, but it leaves a line on the board or the floor, because they are rough". The rest of the group agreed on that.

Some members of group D tried to hold a pen with wet hands and they observed that it slipped. Someone mentioned that he had tried to write something down that

morning while he had some butter in his hand from the toast he was eating earlier and he noticed that he had difficulties in holding the pen. Another pupil mentioned that he also had difficulties in writing with sweaty hands just after playing football in one of the school breaks, some days ago. He noticed that it happened because his hand was slippery. Thus, the group agreed that water, sweat or butter make our hands slippery so we cannot easily hold a pen.

Two of the members of group E had skidded with their bikes due to a slippery road and they talked about their experience within the group. The pupil that had looked for the book showed the rest of the group some pictures of bikes and motorbikes slipping over oily or icy roads. He mentioned that it all happens because the oil makes the road slippery and as a consequence the bikes cannot have a good "grip" so "you can't keep balance and you fall". They all agreed that oil on the road is very dangerous and we must be very careful.

After the group discussions the children spent some time writing down their report. The teacher reminded them that they had to write about:

- their opinion concerning the reason(s) why the certain phenomena happen, and
- what they thought was the common thing or concept in all of the situations they had examined.

Their written reports were as follows:

Group A:

When we try to walk on ice we slip over because it is slippery, smooth and flat. If we have rubber shoes, like trainers, it will be more difficult to slip. If we have ice skates on, we can have an advantage of slipping on the ice. All the questions are about slipping and gripping.

Group B:

When we push the book, our force is grater at the start of our push. One reason why our push gets weaker is

because gravity pulls it down and that makes it stop. Another reason is the surface of the table, which slows it down. If it is smooth, the book will slide further. The common thing in the questions is about sliding, grip and surfaces.

Group C:

The chalk does not write on the glass. The window glass is smooth and that's why the chalk doesn't leave a line. If it was rough like the board or the floor the chalk would leave a line. In all of the given questions gripping and surfaces are in common.

Group D:

When your hand is wet or sweaty and you try to write with a pen, your hand slips down the pen. It does this because the grip is slippery and the hand used to have grip, but it lost it when it got wet. If your hand is dry it has a good grip. All the questions are about gripping and slipping surfaces.

Group E:

When we go over oil with our bikes we slip because there is no grip. We slip because the oil spoils the grip on the tyres and it is difficult to keep balance. The same happens on ice. The common thing is slipping, gripping and surfaces.

These reports mainly reflect the discussion that took place within the groups. A representative from each group read the group's report to the whole class and then she or he went to stick the paper on the wall, so everybody could look at it later on. After the report of each group was read, the teacher invited the pupils to make some comments on the ideas that the group had expressed.

Group A received a comment from a pupil concerning a special kind of shoe with spikes that some people wear in order not to slip on the ice. She claimed that she had seen such shoes and they worked effectively because they could make holes in the ice and grip firmly.

Group B received a comment concerning the surface of the table. Some pupils noticed that if the surface of the table was rougher the book would slide a shorter distance with the same push. A couple of other pupils mentioned again the importance of gravity, because "it is gravity that presses the book on the table and then the table slows it down". This idea seemed to be plausible and generally acceptable by their fellow pupils.

The report by group C was accepted with astonishment from the rest of the class, although they had noticed the earlier activities of the group. Some pupils took a piece of chalk and tried to write on the window glass. They couldn't believe that the chalk did not leave a noticeable trace, but as someone mentioned "it could be the chalk, you know; this one is a bit hard, I have seen some softer ones. They could write on the glass". Some pupils agreed on that, but looked a bit puzzled. The teacher proposed that they could try it again when someone would bring a "softer piece of chalk".

Group D received a similar comment, to that of group B, in reference to the surface of the pen this time. Someone observed that some pens have a very rough surface and it could be possible to hold them firmly, even with wet or sweaty hands. She demonstrated her opinion with a of one of those pens. The rest of the class agreed on her comment. Someone else also had the impression that if we could press the pen very hard, it wouldn't slip down our hand, but he said that he couldn't show it to the rest of the class and that "it would be difficult to press hard when your hands slip all the time".

One comment that group E received was that it is not a matter of keeping balance on a slippery road, because "without any grip on the tyres, you'll fall anyway; there's

nothing you can do to stop it". One pupil mentioned that she had slipped with her bike when the front tyre went over a banana skin. Some pupils agreed that the banana skin is also very slippery, even when someone walks on the road.

All of the groups seemed to agree that the common "thing" or the common concept behind the five "triggering instances" was about "gripping", "slipping" and "the nature of surfaces". During a more general discussion that followed the children made some generalisations and inferences. They said things like the following:

- if surfaces are "smooth", "even" or "flat" then they are slippery or they slide easier. If they are rough they grip more;
- if you don't have good grip you slip and fall down or you can't catch things because they slip out of your hands;
- ice, oil, water and sometimes a banana skin can be very slippery and may cause accidents.

These statements were put together on a small poster and they were stuck on the wall, next to the children's writings, so they could be easily recalled and referred to during the following lesson. The session ended with the teacher telling the children that they were going to take a closer look and examine more carefully this "gripping and slipping" in the following lesson which was going to be held in two days time (on that following Thursday). He also mentioned that they were going to do some investigations and try to find out why things grip or slip. The children seemed to like the idea and the reacted in a rather positive way.

4.2.4. A commentary on the introductory session

It was rather surprising to see the children reacting spontaneously to the "triggering instances" by organising investigative activities by themselves. They wanted to see on their own what was happening in the situations they had to examine. During the break, the teacher mentioned that they often did so if they found something

interesting and they felt they had to check it for themselves. They would look for further information or try to investigate a certain situation in order to express an opinion. He also mentioned that he felt very proud of that achievement, since it took him a lot of time and effort "to make them act in an investigative and creative way and feel free to present and exchange opinions and critique".

From what went on in class, it is quite obvious that the children could easily grasp the idea of "gripping" and "slipping" of surfaces as an everyday phenomenon and they could also reason about it. Their reasoning was rather intuitive and they thought that gripping and slipping are related to the nature of surfaces. They proved to be good observers and they also developed some very creative reasoning to support their intuitive ideas or they could generate creative alternatives for certain situations. Some examples of these could be the spike shoes that can grip on ice, the "softer chalk" that could possibly write on glass, the observed differences on the surfaces of the sliding book on the table, the banana skin that makes a person's shoe slip, or a bicycle rider who can't keep balance on an oily road, the case of the special pens that have a better grip etc.

Their intuitive conception of gripping mainly seems to be a reification since it is "*something* that you have and you can hold on or catch on something else" or it is "*something* that you don't have and you slip and fall". For example, the hand "lost its grip when it got wet" or "it has a good grip" if it is dry. They also seem to have this "reified conception" closely related to the surfaces in contact. Thus, it is "something" that the surfaces have or have not which gives them gripping qualities or makes them slippery. For example "we slip on ice because it is slippery, smooth and flat" or "the window glass is smooth and that's why the chalk doesn't leave a line" or the fact that we slip with the bicycle on an oily road because "the oil spoils the grip on the tyres". Furthermore, in certain cases, they seem to relate their conception of gripping with the concept of gravity which somehow "sticks the book on the table", or as they wrote, "gravity pulls it down and makes it stop".

The children don't seem to associate explicitly their conception of "gripping" and "slipping" with the concept of force. They do not appear to be considering that "gripping" could be a "push" or a "pull", although sometimes in the pre-intervention interviews they seem to be able to call "gripping" "something like a force" and identify it in an intelligible way. However, the word "friction" was not mentioned during the introductory session, although it was uttered in one of the pre-intervention interviews (cf. what (**Ph**) says in § 4.1).

4.2.5. The second session

The second session was an afternoon session, two days after the introductory session, on the Thursday of that week. It was a longer session of approximately one hour and twenty minutes (1.20') without any break. There was just a short pause on the hour, for a couple of minutes, to move away from the experimental activities and on to a whole class discussion period for the last twenty minutes or so. Normally, that last period of time was used for silent reading, but for the purposes of this inquiry it was agreed to do science for all of the session.

The main foci of the second session were to:

- elicit some of the children's ideas or alternative conceptions, concerning frictional phenomena and make them explicit to everybody involved in the learning process
- provide opportunities for learners to question, investigate and experiment on the nature of frictional force
- encourage learners to acquire new conceptions on frictional phenomena using an explanatory analogy and apply it in various related instances.

These foci would be achieved by means of a series of teaching events and activities encouraging the learners to:

- become aware of their intuitive ideas concerning certain frictional phenomena (e.g. a stationary book on a tilted table) and make them explicit in class by

expressing and discussing these ideas and possibly by taking a poll at the end of this process

- test these alternative ideas, in an investigative way, by conducting experiments with blocks of wood, which the children would slide on different surfaces on their tables (e.g. on plastic laminate and on different kinds of sandpaper)
- consider the plausibility of a "scientific explanation" for the nature of friction (static and sliding) which will be presented through the analogy of a jigsaw puzzle and attempt to compare this explanation with prior ideas within the context of new inferences.
- apply the newly acquired ideas to some other similar instances referring to friction, in order to check their plausibility and support their opinions within the context of classroom discussion.

The session started with the teacher telling the children that they could find some pieces of wood and some other equipment like weights and pulleys on their desks. But before they experimented with them, they would briefly revise what had happened in the previous session. The teacher mentioned that they were discussing gripping and slipping and reminded them some of their ideas on the topic, by reading some of the papers that they had stuck on the wall during the previous lesson. The children mentioned that they remembered all about it and they wanted to investigate further these issues as they had already agreed.

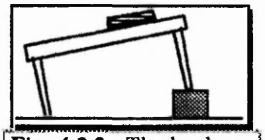


Fig. 4.2.2: The book on the tilted table.

After that, he stood behind his table and put a book on it. He lifted the table a little bit from one of the sides and asked the pupils what they observed. They replied that the book was stationary on the table and it wouldn't move at all, basically because the table was not steep enough and there was no reason for the book to start sliding. No other alternative response was expressed at that moment. Then the teacher lifted the table a bit more and asked again why the book didn't move on the table towards the end of it and the children expressed their ideas by producing some answers which were written on the board by one of them. Here they are presented in the following table:

Learners' ideas	Results of the poll
• the table is still not steep enough; we should tilt it more for the book to start sliding	**9**
• gravity is somehow sticking the book on the table and it can't move because it's pushing it down onto the table	**6**
• the surface of the table is somehow holding the book; it's like the table is pulling it in the opposite direction; some kind of force is holding it up	**4**
• the book grips on the table like a tyre of a car on the road	**1**
• the book would slide only if we put some rollers under it, like pens or pencils; it wouldn't stick on the table then	**1**

Table 4.2.2: Children's alternative ideas concerning the "book on the tilted table" situation together with the results of the poll which was held immediately after the elicitation of their ideas.

As soon as these ideas were written on the board the teacher asked the children to put their ideas to a vote. Each pupil should vote only once. The results of this poll are presented on the right column of Table 4.2.2. The majority of the children believed that the book was not sliding because the table was not tilted enough while others felt that gravity plays an important role in holding the book on the table. Only four or five of them thought that the surface of the table or the surface of the book had something to do with the gripping of the book on the table. One of them even presented some sort of perceptual analogy, that of the gripping automobile tyre. There was also an alternative idea expressed from one of the children who mainly focused his attention on proposing a way of sliding, or in fact rolling, the book on the table with the use of some rollers. The class democratically decided to record this idea and to include it in their poll, although most of the children felt that it was about a different kind of problem or at least a different aspect of the problem.

After the poll the teacher moved on to present the material that the children had on their desks and elicit some ideas for further investigation.

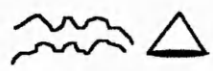
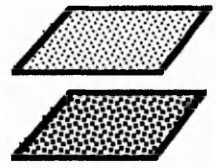
A verbal description of the objects on the tables	*A pictorial representation of the objects on the tables*
• three (3) blocks of wood in a cuboid shape (4x8x15 cm), each weighing approximately 4.5 N. All of these blocks had a small hook screwed into one of their smallest sides.	
• one (1) pulley fixed on one edge of each table. It was a plastic pulley which was attached on the table with the aid of a G cramp.	
• some weights in the shape of small disks (10 of 1N, 10 of 0.5 N, 10 of 0.3 N and 15 of 0.1 N)	
• some pieces of string and a small plastic tray which was used to put the weights in. The tray weighed approximately 0.1 N.	
• one newton meter (dynamometer) which could measure the weight in Newtons. The children were already familiar with it, since they had already used it in measuring the weight of objects.	
• a parallelogram piece of sandpaper was also available on all of the tables apart from the first one. Its dimensions were roughly 1*m* in length and 35*cm* in width. The sandpaper was "fine" or "softer" for two of the tables and "rough" or "harder" for the other two.	

Table 4.2.3: The equipment that was available for the children on their tables.

He stood in front of one of the tables, picked up each of these items, showed it to the children and briefly described what it was (see Table 4.2.3). Then he asked the children what they could possibly do with this kind of equipment, in relation to their previously discussed ideas on "gripping and slipping". Some children said that they should try to slide the blocks of wood on the table and somehow they should try to measure their "grip" on the table. Some other mentioned that they could do that with one, two or three blocks to study the differences. In the beginning, they had difficulties in finding out about a probable use of the pulley, the tray and the weights. It seemed that most of the children wanted to start their experimentation on the sliding of the wooden blocks by using their hands for that task. Then, rather

unexpectedly, a couple of children came up with an idea in the following, recorded, short dialogue:

L_1: I get it .. / we can use this piece of string to pull the block this way ... we can tie it to that .. kind of hook and .. we can pull it with our hand .. but we can also .. use the pulley ..

T: >> hmm ... that's interesting .. in what way .. /

L_1: well .. we can tie this plastic tray at the end of that string and ... use the pulley .. I mean pass it over here ... then use the weights to pull the block along the table ..

[he demonstrated this with his hands and the equipment]

L_2: yes ... it will be like .. like we pull it with our hand .. but this way we can find out how much weight we need to pull it along .. we can measure it ..

T: that's a good idea .. I think we should try that .. we can also use those pieces of sandpaper and see if things are any different ..

At that moment, approximately twenty five minutes had elapsed from the beginning of the session. The children had briefly discussed and had generally decided how they were going to investigate the sliding of the blocks of wood on the table by using the given equipment. The teacher mentioned that he had prepared a leaflet for them, in an attempt to organise their activities and he distributed it to all of the groups (see fig. 4.2.3).[2] He also provided the groups with blank A_4 pages to be used for the recording of their investigations. He went on to demonstrate how to set up the experiment according to the respective drawing in the "investigation leaflet". In fact he helped the children in the first group (Group 1) to tie a piece of string on the hook of one of the blocks of wood, pass the string over the pulley and tie the plastic tray at the end of it, where the weights could be placed. Then he asked the rest of the groups to do the same thing carefully, although they had already started doing that in parallel with the first group. A couple of minutes later, he briefly described the activities which were included in the "investigation leaflet" and said that he would answer any further explanatory questions as soon as the groups started their investigations. He

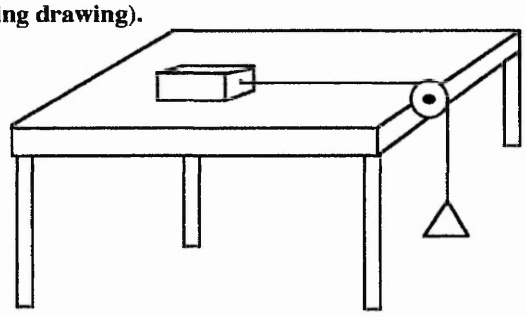
[2] This leaflet was in fact a product of the collaboration of the teacher and the researcher.

stressed the importance of *safety* and *fair testing* by mentioning that they all had to be very careful, show mutual respect for the effort of each other and that they had to perform the activities and measure things as attentively as possible. After that, he started going around the groups in order to help the children with the management of the available equipment for their investigation. At this stage, the teacher received some help from the researcher, who participated in this process as a teacher assistant.

INVESTIGATION

TABLE 1.

There are some blocks of wood on your table. You may tie a piece of string on one of these blocks and then pass it around a pulley which is fixed at the edge of the table. You may tie a plastic tray at the end of the string. You can put some weights there (see the following drawing).



ACTIVITIES

1. **Weigh your block of wood.**
2. **Add carefully weights on the tray until the block starts sliding gently.**
3. **Note how much weight you have to use in order to slide the block of wood on the table.**
4. **Compare this force with the weight of the block. What do you observe?**
5. **Add another block of wood on top of the one you already have on the table. Repeat activities 2 & 3.**
6. **Compare the force you had to use in order to slide the blocks of wood on the table with their weight. What do you observe? Record your observations.**

Group work

Group leader:
Performer:
Observer(s):
Scribe:

Attention: Add the weights gently on the tray. Try not to move or shake the table while you are doing your investigation.

Fig. 4.2.3: The leaflet that was distributed to the children during the second session of the teaching intervention. This one is from table 1, where group one was working. They had to slide their blocks of wood on their desk, which was covered with plastic laminate.

The children worked in five groups as they usually did whenever they had to do some group work (cf. § 4.2.2). Each group was provided with the leaflet (see fig. 4.2.3)

with the activities they were about to carry out. The children were used to being assigned certain roles to perform within the group and they usually wanted to try a different role every time. They often switched around these roles, from time to time, during the course of the group work activities. It usually took the children a couple of minutes to decide what role would be assigned to whom each time. The designated roles within each group were:

- **Group leader** — The person who was managing the group by asking people to do things, having the overall control of the group. He or she was usually reporting the work of the group.
- **Performer** — The person who was making things happen with the assistance of the other members of the group.
- **Observer** — The person(s) who were responsible for the observation of the activities and the measurement of the variables.
- **Scribe** — The person who was responsible for keeping records of all of the data collected by the group.

It was often the case that different groups worked on different aspects of the same phenomenon or problem in order to gain a more holistic grasp of it. The first group (Group 1, Table 1) was going to slide the blocks of wood on the surface of the desk, which was covered with plastic laminate. Groups two and five were going to experiment on sliding their blocks of wood over a piece, or actually a strip, of "fine" sandpaper which was stuck on the desk with insulating tape. Groups three and four were going to slide their blocks of wood on a piece of "rough" sandpaper (see fig. 4.2.4). At this stage, each group had to work independently, record and elaborate their observations, raise some conclusions and then make a report, which would be presented in the whole class session for further discussion.

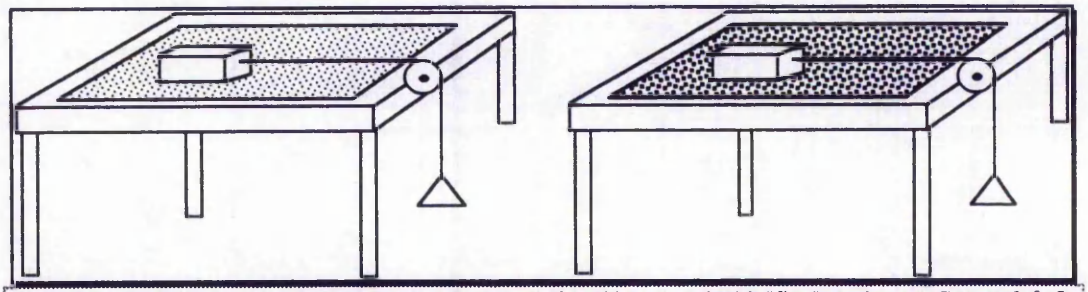


Fig. 4.2.4: On the left there is a pictorial representation of a table covered with "fine" sandpaper (Groups 2 & 5) and on the right there is another table covered with 'rough' sandpaper (Groups 3 & 4).

The teacher asked a child in each group to weigh one block of wood with the newton meter. They did so and they found that each block weighed **4.5 Newtons.** Then, he said that it would be helpful to give them an idea of how they could organise the recording of their data. Thus, he designed the following Table on the chalkboard:

Weight of the block(s)	Weights on the tray	Effect on the block(s)	
		No sliding	Sliding

The learners had to write down the weight of the block(s) which had to be kept constant. Then, they could gradually add weights on the tray and record their effect on the sliding of the block(s) by ticking the respective box. At the end of the process, they would have a complete record of measurements referring to their experimentation. The scribes of each group copied the table on the blank A_4 paper and they got ready to start recording the observations and measurements of the group.

At that moment, and before the children started their experimentation, the teacher asked them to predict how much weight they would have to use in order to make the block of wood start sliding on the desk. The children in the first group said that they would have to use as much weight as the weight of the block itself, because otherwise it wouldn't slide. They mentioned that they would need "an equal force pulling the block along the desk". The children in the second and fifth group ("fine" sandpaper)

said that they would have to use more weight than the weight of the block because "the sandpaper is rougher and they would need more force to pull it along the desk". The children in the third and fourth group ("rough" sandpaper) said that they would have to use even more weight than the children in the previous two groups because their sandpaper "was a lot rougher" and therefore they would need more pulling force, because "the block would grip more". The teacher did not express an opinion, but asked the learners to check their ideas in action and advised all of the groups to increase the weights gradually in order to be able to make more accurate measurements. He mentioned though, that it would be better and more *fair* if they placed their block(s) at a certain "starting line" before they attempted to slide them and he suggested that all of the groups should draw a "starting line" on their tables using a thick marker.

The groups started their experimentation and the scribes started recording the data of each group. The classroom was filled with the noise of busy children who were investigating and challenging their ideas. At first, all of the groups experimented with one block of wood and they were surprised when they found out that the block would start sliding with a smaller pulling force than its weight. In the case of fine sandpaper the pulling force from the weights had to be a roughly half of the weight of the block and in the case of the rough sandpaper the pulling force had to be a bit more than half of the weight of the block. After they had experimented with one block of wood, they continued experimenting with two, and in some groups even with three blocks. During the experimentation the teacher and the researcher were moving around the groups and they were helping the children, whenever it was necessary. After twenty five minutes or so, the groups were ready to present their work. The first group came up with the following Table:

Weight of the block(s)	Weights on the tray	Effect on the block(s)	
		No sliding	Sliding
4.5 N	0.2 N	✓	
4.5 N	0.3	✓	
4.5 N	0.4 N	✓	
4.5 N	0.5 N	✓	
4.5 N	0.6 N	✓	
4.5 N	0.7 N	✓	
4.5 N	0.8 N	✓	
4.5 N	0.9 N	✓	
4.5 N	1 N	✓	
4.5 N	1.1 N		✓
9 N	1.1 N	✓	
9 N	1.4 N	✓	
9 N	1.6 N	✓	
9 N	1.9 N	✓	
9 N	2.1 N	✓	
9 N	2.2 N		✓

Table 4.2.4: *Group 1*. A representation of the record they kept when they experimented with one and two blocks of wood.

The second and fifth group experimented with the sliding of blocks of wood on a piece of "fine" sandpaper. In the beginning both of the groups experimented with one block of wood and they came up with roughly the same measurements. These measurements can be represented in the following Table:

Weight of the block(s)	Weights on the tray	Effect on the block(s)	
		No sliding	Sliding
4.5 N	0.2 N	✓	
4.5 N	0.3	✓	
4.5 N	0.5 N	✓	
4.5 N	0.7 N	✓	
4.5 N	0.9 N	✓	
4.5 N	1.1 N	✓	
4.5 N	1.4 N	✓	
4.5 N	1.6 N	✓	
4.5 N	1.9 N	✓	
4.5 N	2.1 N	✓	
4.5 N	2.4 N		✓

Table 4.2.5: ***Groups 2 & 5.*** A representation of the record they kept when they experimented with one block of wood on "fine" sandpaper.

After both of the groups (two and five) had experimented with one block of wood on a piece of "fine" sandpaper with roughly the same recorded measurements, the teacher asked the second group to experiment with two blocks and the fifth group to experiment with three blocks. The second group produced the following Table, in their attempt to slide the two blocks of wood:

Weight of the block(s)	Weights on the tray	Effect on the block(s)	
		No sliding	Sliding
9 N	2.1 N	✓	
9 N	2.4 N	✓	
9 N	2.6 N	✓	
9 N	3.1 N	✓	
9 N	3.4 N	✓	

9 N	3.6 N	✓	
9 N	3.9 N	✓	
9 N	4.1 N	✓	
9 N	4.4 N	✓	
9 N	4.6 N	✓	
9 N	4.7N		✓

Table 4.2.6: ***Group 2.*** A representation of the record they kept when they experimented with two blocks of wood on "fine" sandpaper.

The fifth group produced the following Table in their attempt to slide three blocks of wood on "fine" sandpaper:

Weight of the block(s)	Weights on the tray	Effect on the block(s)	
		No sliding	Sliding
13.5 N	4.1 N	✓	
13.5 N	4.6 N	✓	
13.5 N	5.1 N	✓	
13.5 N	5.6 N	✓	
13.5 N	6.1 N	✓	
13.5 N	6.6 N	✓	
13.5 N	6.7 N	✓	

13.5 N	1N 1N 1N 1N 1N 1N 0.5N 0.3N 6.9 N	✓	
13.5 N	1N 1N 1N 1N 1N 1N 0.5N 0.3N 0.1N 7 N	✓	
13.5 N	1N 1N 1N 1N 1N 1N 1N 0.1N 7.2 N		✓

Table 4.2.7: ***Group 5.*** A representation of the record they kept when they experimented with three blocks of wood on "fine" sandpaper.

The third and fourth group experimented with "rough" sandpaper and for one block of wood they produced roughly the same table of recorded measurements. This Table could be represented as follows:

Weight of the block(s)	Weights on the tray	Effect on the block(s)	
		Not sliding	Sliding
4.5 N	0.1N 0.2 N	✓	
4.5 N	0.1N 0.1N 0.3	✓	
4.5 N	0.3N 0.1N 0.5 N	✓	
4.5 N	0.5N 0.1N 0.7 N	✓	
4.5 N	0.5N 0.3N 0.9 N	✓	
4.5 N	1N 1.1 N	✓	
4.5 N	1N 0.3N 1.4 N	✓	
4.5 N	1N 0.5N 1.6 N	✓	
4.5 N	1N 0.5N 0.3N 1.9 N	✓	
4.5 N	1N 0.5N 0.5N 2.1 N	✓	
4.5 N	1N 1N 0.3N 2.4 N	✓	
4.5 N	1N 1N 0.3N 0.1N 2.5 N	✓	
4.5 N	1N 1N 0.5N 2.6 N	✓	
4.5 N	1N 1N 0.5N 0.1N 2.7 N		✓

Table 4.2.8: ***Groups 3 & 4.*** A representation of the record they kept when they experimented with one block of wood on "rough" sandpaper.

After both of these groups had completed their measurements with one block of wood and they had roughly come up with the same conclusions, the teacher asked the third group to experiment with two blocks of wood and the fourth group to experiment with three blocks of wood. Thus, the second group came up with a Table that looked like the following:

Weight of the block(s)	Weights on the tray	Effect on the block(s)	
		No sliding	Sliding
9 N	2.4 N	✓	
9 N	2.6 N	✓	
9 N	3.1 N	✓	
9 N	3.4 N	✓	
9 N	3.6 N	✓	
9 N	3.7N	✓	
9 N	3.9N	✓	
9 N	4.1N	✓	
9 N	4.4N	✓	
9 N	4.6N	✓	
9 N	4.9N	✓	
9 N	5.1N	✓	
9 N	5.4 N		✓

Table 4.2.9: ***Group 3.*** A representation of the record they kept when they experimented with two blocks of wood on "rough" sandpaper.

The fourth group experimented with three blocks of wood and they came up with a Table that looked like the following:

Weight of the block(s)	Weights on the tray	Effect on the block(s)	
		No sliding	Sliding
13.5 N	4.1 N	✓	
13.5 N	4.6 N	✓	
13.5 N	5.1 N	✓	
13.5 N	5.6 N	✓	
13.5 N	6.1 N	✓	
13.5 N	6.6 N	✓	
13.5 N	6.7 N	✓	
13.5 N	7.1 N	✓	
13.5 N	7.6 N	✓	
13.5 N	7.9 N	✓	
13.5 N	8.2 N		✓

Table 4.2.10: ***Group 4.*** A representation of the record they kept when they experimented with three blocks of wood on "rough" sandpaper.

After each group had completed their tasks and had finished their activities, the teacher asked the leaders of each group to report their results to the whole class and

then stick the paper with their measurements and comments on the wall, next to the other posters and papers.

The first group presented their measurements and mentioned that they had found out that one block of wood would start sliding on the table with a "pulling force" of **1.1 Newtons**. They had compared the weight of the block with the "pulling force" of the weights and the tray and they inferred that it was approximately one fourth ($^1/_4$) of the weight of the block and this was rather astonishing, according to their predictions before the experiments. They thought that the "gripping force"[3] would be a "lot stronger" and that the weight of the block would somehow stick it on the table. They expected that "a much stronger force" would be needed to pull it along. They were now convinced that although the "gripping force" holds the block back in its place, "gravity" or the "weight of the block" just "sticks it on the desk" and the "gripping force" resists the "pulling force" of the weights "only by one fourth of the weight of the block". One of the children in this group had the idea to put the block of wood on some pencils and then try to pull it along the table with the aid of the weights. He seemed surprised when he found out that it would only take a pulling force of 0.5 N to start sliding. When he announced that in class, some children commented that it is always easier to move things when they are on wheels or rollers and for example they referred to suitcases with wheels, skateboards and bicycles. They concluded that the block of wood slides rather easily on the desk covered with plastic laminate, although it would slide a lot easier if it was put on pencils or rollers.

The second group, which had experimented on "fine" sandpaper, found out that one block of wood would start sliding along the desk with a "pulling force" of **2.4 Newtons**. They compared this "pulling force" with the weight of the block and they inferred that it was roughly half ($\sim^1/_2$) of its weight. They mentioned that they expected the "gripping force" to be greater and they were rather surprised with their

[3] The terms "pulling force" and "gripping force" are put in speech marks because they are the terms that the children used to describe the respective forces.

results. Nevertheless, they admitted that they were "probably fooled by the gripping force of the book on the tilted table" which they sensed that was a slightly different case of the same phenomenon. The fifth group who had also experimented with one block of wood on the surface of the same kind of 'fine' sandpaper and they came up with the same final measurement (2.4 N). After that, the teacher asked the children of the second group to experiment with two blocks of wood and the fifth group to experiment with three blocks of wood. They came up with analogous measurements and results. Two blocks of wood, which weighed **9 Newtons**, were slid by a "pulling force" of **4.7 Newtons**, which was approximately half of the weight of the blocks (second group). Three blocks of wood, which weighed **13.5 Newtons**, were slid by a "pulling force" of **7.2 Newtons**, which was again approximately half of the weight of the blocks (fifth group). After both of these groups had exposed their results in class they inferred that for the "fine" sandpaper they needed a "pulling force" of approximately half of the weight of the block or set of blocks to make them start sliding on the tabletop. They recognised that the "gripping force" was hindering the sliding of the block(s) and that in the case of the sandpaper it was more than in the case of the plastic laminate surface of the table, mainly due to the "roughness" of the surface of the sandpaper. They also observed that while the block(s) was sliding along the surface of the sandpaper, it left a visible trace of "tiny bits of wood" on the black-coloured surface of the sandpaper. They claimed that these "tiny bits of wood" actually snap off from its lower surface because "the block can't hold them since the "gripping force" is pulling on the opposite direction and that tears them to tiny pieces".

The third group who had experimented with rough sandpaper found out that one block of wood (**4.5 N weight**) needed a "pulling force" of **2.7 Newtons** to start sliding on the desk. They compared it with the weight of the block and claimed that it was a bit more than half of the weight of the block and **0.3 Newtons** more than the respective "pulling force" that the block needed to start sliding on the "fine" sandpaper. One of the members of the group did more calculations and proved that

the "pulling force" was "exactly $^{3}/_{5}$ of the weight of the block". The fourth group experimented under the same circumstances and came up with approximately the same results for one block of wood on "rough" sandpaper. While they were experimenting though, a small problem appeared for a moment, as they had to put 2.8 Newtons for one block to start sliding on the tabletop. The third group had finished that part of their investigation earlier and somehow their measurement had become known to the fourth group. They were puzzled for a moment, but the scribe of the group proposed to repeat the experiment. They did so, and this time the block started sliding with a "pulling force" of 2.7 Newtons. They thought that something had gone wrong the first time and they mentioned that "it was a small difference", and that they "shouldn't worry too much about it". At that time, the teacher asked them to go on to the next phase of their investigation where they had to try to slide three blocks of wood (**13.5 N weight**) on the surface of the table covered with "rough" sandpaper. After a while, they found out that a "pulling force" of **8.2 Newtons** had to be exerted on the three blocks to start sliding. They compared it with the weight of the three blocks and they inferred that it was "more than half of the weight of the blocks". They also did a calculation and concluded that it was approximately $^{3}/_{5}$ of the weight of the blocks.

The third group simultaneously experimented with two blocks of wood (**9 N weight**) on the same kind of "rough" sandpaper. They found out that the block would start sliding with a "pulling force" of **5.4 Newtons** which was inferred to be more than half of the weight of the block. They mentioned that the comparison they had made earlier for one block was still valid, thus the "pulling force" was "exactly $^{3}/_{5}$ of the weight of the two blocks". Both of these two groups agreed that the "rough" sandpaper "had more grip", or that "the gripping force was stronger" and that a the "pulling force" needed for the block(s) to start sliding was more than any other case. They also noticed the tiny bits of wood that snapped off from the surface of the wooden block(s) and they agreed with the explanation that the previous two groups had given about that phenomenon.

After all groups had finished the presentation and analysis of their work, the teacher invited all of the children to discuss further their investigation. He then asked them if they thought that there was any relation between the "pulling force" and the "gripping force" or the "grip", as they often referred to it. One child from the first group mentioned that they were both forces and since they pulled the block(s) in opposite directions, they were both "pulling forces". There was no objection, so the class seemed to agree on that. Another child from the fourth group mentioned that the "gripping force" was strong in the beginning keeping the block in its place, stationary on the table. But, as they kept adding weights, the "gripping force" was becoming "weaker", until it eventually "had to let the block go" since "it had to start sliding on the surface of the table at some time". At that moment, the teacher asked the learners if they thought that just before the sliding had started, both of these forces ("pulling" and "gripping" forces) were opposite and equal. They thought about it for a couple of seconds and then a child from the fifth group agreed that the two forces were equal just before the block started sliding, but they were pointing in opposite directions. "*I think I get it ..*" another child from the same group yelled. "*Just before sliding .. if we measure .. the pulling force .. it's just like we measure the gripping force .. because they are equal .. and they should be the same .. although they are pulling the block in opposite directions*". "*So we know how much .. the gripping force is then*" the first child added. The rest of the class seemed to agree with that and the teacher mentioned that it was a very interesting point.

After that, the teacher went on with a short presentation phase and stated that "friction" is the word that scientists use for the "gripping force" which they had been investigating so far and put forward some questions about the nature of friction. He asked the learners how they thought that this gripping occurred and what was actually happening between the surface of the block and the surface of the desk. The children mentioned that the surfaces were rough or in some cases very rough and they were "gripping", "catching" or they were "holding very tight with each the other". The teacher mentioned that those were all very interesting explanations and proposed an

analogy to visualise this mechanism of friction. The teacher had prepared the material for an analogy on friction with two fragments of a jigsaw puzzle which was horizontally separated in the middle. Both of fragments were glued on pieces of cardboard of different colour (blue and red) and then cut around (see fig. 4.2.5). In this form they were put up on the chalkboard, one very close to the other. The teacher explained that the red fragment could symbolise the surface of the table and the blue fragment the surface of the book, block etc., referring to cases they had already examined.

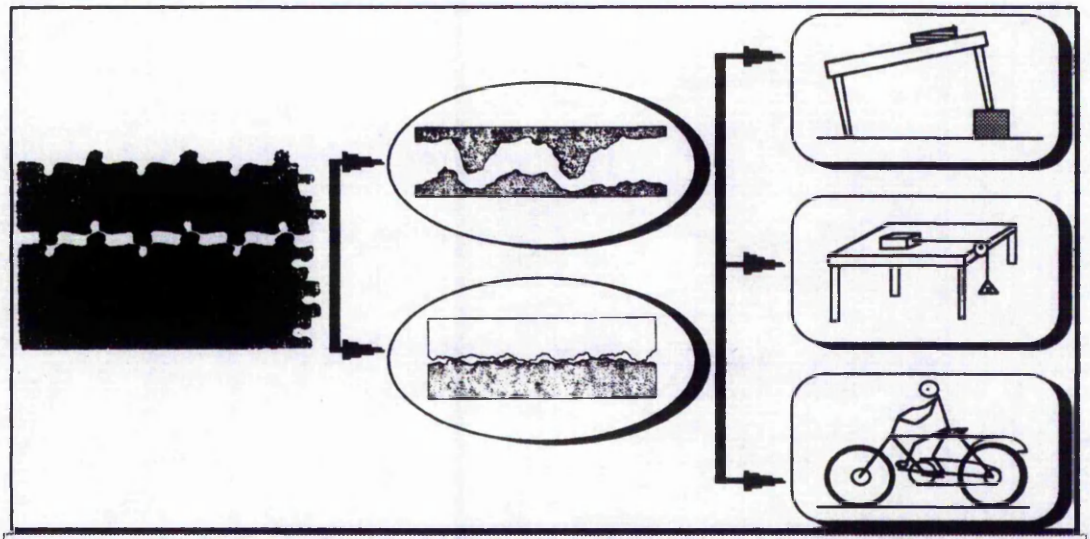


Fig. 4.2.5: A pictorial representation of a teaching analogy with the jigsaw puzzle (**cf. § 1.3.2**). The *analog* (or *anchor situation*) is the two fragments of the jigsaw puzzle, the pictures of two surfaces touching each other and an equivalent enlargement act as *bridging cases* and the situations of the stationary book on the tilted table *(static friction)*, the block of wood sliding on the table pulled by some weights *(sliding friction)* and the moving bicycle *(rolling friction)* are various *target situations* which can be seen through the analogy (**cf. Appendix I**).[4]

The teacher also used two drawings on A_4 paper to illustrate this analogy. One of the drawings depicted two surfaces touching each other. The other depicted an enlargement of a section of the touching surfaces of the first drawing (see fig. 4.2.5 & Appendix VII). The teacher put them up on the chalkboard next to the jigsaw and mentioned that all of the surfaces they had examined so far were rough and they had "peaks and valleys"[5] just like the two fragments of the jigsaw puzzle. When such

[4] The target situation of the rolling bicycle was discussed in the beginning of the third session, but it is presented here as a situation rolling friction

[5] By saying that, the teacher provided the children with a large scale analogy of the nature of surfaces being like a landscape with "picks and valleys".

surfaces come to contact one is getting inside the other and somehow they "*interlock with each other. This creates friction which may hinder the movement of the block of wood despite the pulling force of the weights or keep the book stationary on the tilted table*".

The children seemed to be rather happy with the analogy of the jigsaw puzzle and they appeared to have grasped the idea of "interlocking surfaces", but a couple of them mentioned that they were not quite sure about what was happening when the block of wood was sliding on the surface of the table. They could understand that there would still be friction on the rubbing surfaces "because you need to keep pulling the block to slide", or "because the book stops sliding on the table when you stop pushing it", but they wondered how the jigsaw puzzle could possibly help them explain that. In other words, they seemed to question the fruitfulness of the analogy for sliding friction.

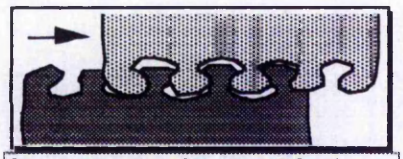


Fig. 4.2.6: Two fragments of a jigsaw puzzle. The upper is moving from left to right, bumping on the surface of the lower fragment.

The teacher said that he was expecting that question. He moved to the chalkboard, grasped the blue fragment of the jigsaw puzzle and begun to slide it from left to right, as close to the red fragment as possible, which was kept stationary (see fig. 4.2.6). The children could see that the upper, blue fragment was bumping up and down. The teacher pointed out that it was hindered from moving freely since some effort was constantly needed to climb up the "peaks" and then slide down the "valleys". He also mentioned that in real cases some tiny parts of both surfaces snap off, something which wouldn't normally happen with the jigsaw puzzle. He went on to imply that friction is created because most surfaces are rough and this appears to be hindering their movement, when we try to slide one over the other. Friction is actually the force that slows down and eventually stops things when they are left to move on their own.

The children appeared to have grasped the metaphorical meaning of the jigsaw puzzle analogy for sliding surfaces (cf. § 1.3.2), since they could now explain more easily situations like a sliding block of wood on the table, a sliding box on the floor, or a sliding book on the table. They sensed that "friction was using up the pushing force" or that "the bumpy surfaces slowed down the book on the table".

The teacher then asked if they thought that there was any friction in situations where wheels (bicycles, cars etc.), or rollers (the pencils they had used in the experiments with the block of wood) are present. The children replied that although things move a lot easier with wheels or rollers, there would still be some friction because surfaces are still "rough" or "bumpy" and they "hit one another" when they come into contact. But, somebody commented that "surfaces touch on one point .. that's why friction is not much".

That's roughly where the second session ended. Before the children went out the teacher had told them to think about all the work they had done and if they had any questions they could always bring them for class discussion during the next session, on the following day.

4.2.6. The third session

The third session was held in the morning of the following day (Friday), but it only lasted for twenty five (25) minutes. For the first fifteen minutes or so, the children raised a couple of questions and discussed them in class. Then, the teacher presented some more practical cases of friction from our everyday life and negotiated them with the children. For the remaining time, they filled in a kind of leaflet, which mainly referred to the nature of frictional force. This was planned and conducted as an on-going form of assessment of the teaching intervention.

Thus, the main intentions of this short session were the following:

- to help the children clarify some ambiguous aspects of friction, by negotiating them in class.
- to present and discuss some practical aspects of friction from our daily life.
- to evaluate children's understanding on the nature of frictional force, by asking them to present a relevant drawing and express their ideas in a written form.

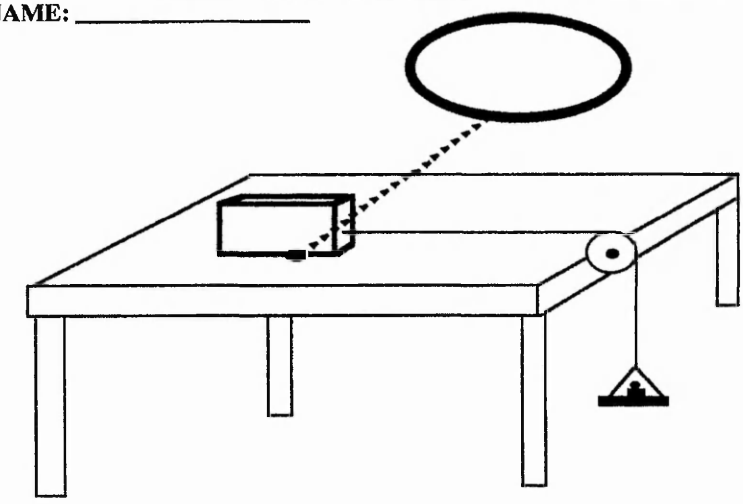
In the beginning of the session the teacher asked the children if they had any questions and a couple of them raised their hands. One child said that she had noticed that when we put oil or grease on rubbing surfaces the force of friction is considerably reduced. She said that she could understand that "grease made the surfaces slippery" but she couldn't understand how that was actually happening. The teacher said that it was an interesting question and invited the rest of the children to express their opinion on this issue. A child raised his hand and tried to give an explanation by saying that when we put grease between two surfaces it is like "filling all the gaps between them .. and this way we make them smooth .. the peaks are also covered with grease and that makes them slippery". Thus, "if the surfaces are smoother and more slippery, friction will be less". The teacher said that it was a very good explanation, but he also added that grease creates a thin layer between the two surfaces and as a result they do not actually touch each other or at least they do not interlock as they did, without any grease between them.

There was one more question about how friction is created when a wheel of a bicycle or a car is moving. The teacher said that it wouldn't be easy to give an answer because it is a bit complicated to explain friction on rolling wheels (cf. Appendix I). He claimed though, that it would be sufficient for the moment, to point out that there is a small area of contact between the wheel and the ground and that's where the two surfaces interlock with each other and create some friction. This gripping is very important for the movement of the bicycle or the car because it actually enables the wheel to roll on the surface of the ground and not spin around without changing its position, similarly like the wheels of a car that spin around on an icy road. He also

mentioned that this gripping slows the bicycle down, when we stop pedalling and consequently, we stop our effort to overcome it. The interlocking of surfaces still occurs over the area that the wheel touches the surface of the ground.

The teacher then asked the children what they thought was happening when they used the brakes while cycling. The children replied that there is a lot of friction between the brake blocks and the wheel because they "rub a lot". He then asked them if they had noticed that the brake blocks get hot after braking for a while. They said that they hadn't noticed that, but one of them said that she had noticed that "the tyres of the car are very hot after a long journey". The teacher mentioned that it is happening because the car tyres are rubbing on the surface of the ground and this creates heat, just like when we rub our hands. Another child said that he had noticed that the brake blocks of his bicycle get worn and he had to change them once in a while. He said he could now understand that it was happening "because of rubbing and friction". The teacher said that it was a very good point and he added that our clothes get worn or sometimes get holes, because we rub them here and there. He said that it is like the rubber we use to erase something on a piece of paper. Both the rubber and part of the paper are rubbed away. He then pointed out that we should all be careful with the brakes of our bicycles and check them regularly to ensure that they have not been worn away to a dangerous state. On the other hand, he commented, we should oil the moving parts of our bicycles for good maintenance and to avoid unnecessary friction and wearing.

NAME: _____



If we magnify a small part of the area of contact of the block of wood and the table, could you draw how would that look like? Use the space in the circle provided.

Write, in your own words, how do you think, this interlocking of surfaces (when one goes into the other), effects friction when we try to slide an object on a surface.

Fig. 4.2.7: The leaflet that the teacher gave to the learners at the end of the teaching intervention.

At that point, there seemed to be no more questions and the teacher said that he was going to give them another leaflet where they had to make a drawing and write a short paragraph about friction (see fig. 4.2.7).

More precisely, they had to draw a magnified section of the touching surfaces of the block of wood and the table and they had to write in their own words how they thought that the interlocking of surfaces effected the creation of friction. They roughly spent ten minutes for this last activity. In an attempt to present an authentic aspect of children's work, some of their drawings and writing are printed and commented in the following paragraphs.

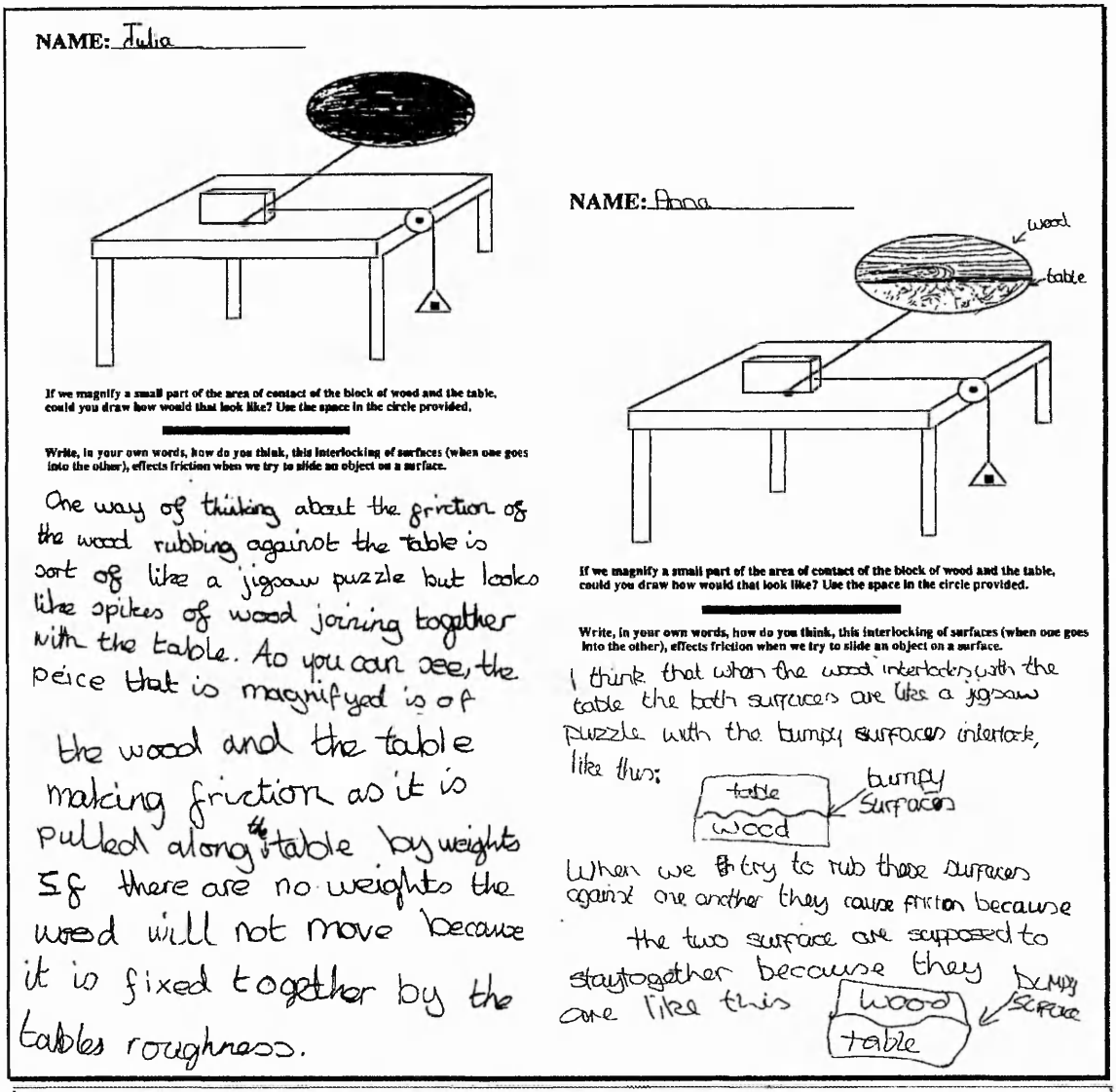


Fig. 4.2.8: Julia's and Anna's drawings and writing

Julia and Anna (see fig. 4.2.8) wrote extensively about their ideas and they both used the analogy of the jigsaw puzzle to illustrate their understanding of the mechanism of friction. They described it like "spikes of wood joining together with the table" (Julia) or "bumpy surfaces that interlock" with each other and this is why they "are supposed stay together" (Anna). Julia comments that the analogy of the jigsaw puzzle is "one way of thinking about friction". She probably means that there are other alternative ways of thinking about it, which had or had not been discussed in class, but she chooses to think about it "this way", because it probably seems to be more fruitful or instrumental for her at the moment. They both use the words "rub" or

"rubbing" which they associate to friction. Their drawings are not very clear, especially Julia's. Anna's drawing identifies the block of wood and the table, but the roughness of the two surfaces is not clearly shown.

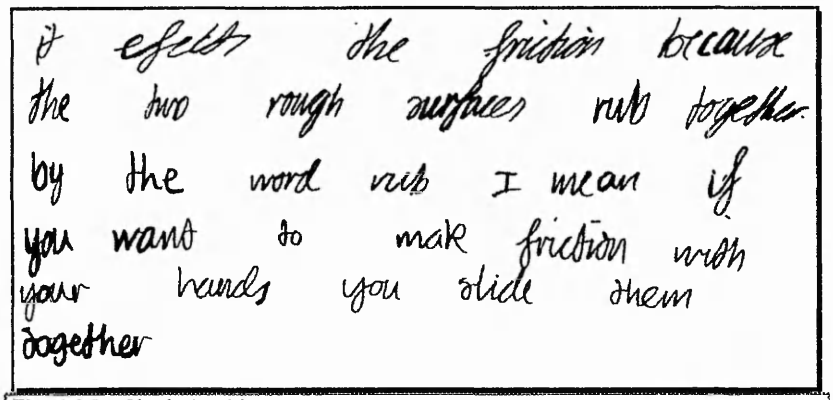


Fig. 4.2.9: Charles' writing.

Charles claims that the interlocking of surfaces effects friction "because the two rough surfaces rub together" and then he gives his own meaning to the word "rub" by referring to the rubbing of hands which you "slide together" if "you want to make friction" (see fig. 4.2.9). He does not refer to anything else and it seems that he has a conception of friction mainly related to surface roughness and rubbing.

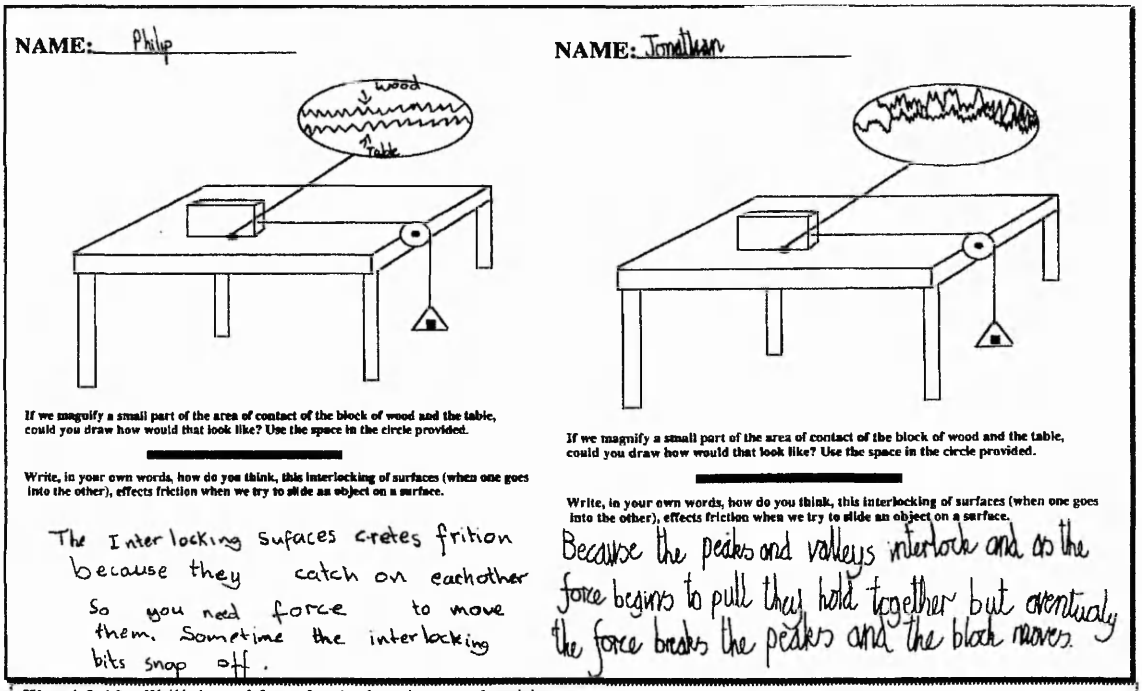


Fig. 4.2.10: Philip's and Jonathan's drawings and writing

Philip and Jonathan made more clear drawings and showed the roughness of the two surfaces. In Jonathan's drawing the interlocking of surfaces is very well illustrated (see fig. 4.2.10). Philip claimed that the interlocking surfaces create friction because "they catch on each other so you need force to move them". He added that "sometimes the interlocking bits snap off", which is very interesting comment. Jonathan claimed that "the peaks and valleys interlock and as the force begins to pull they hold together but eventually the force breaks the peaks and the block moves". His claim that the pulling force "eventually breaks the peaks" is a good description of the maximum degree of static friction just before the sliding of the block starts. After that, static friction becomes sliding friction (cf. Chapter 2).

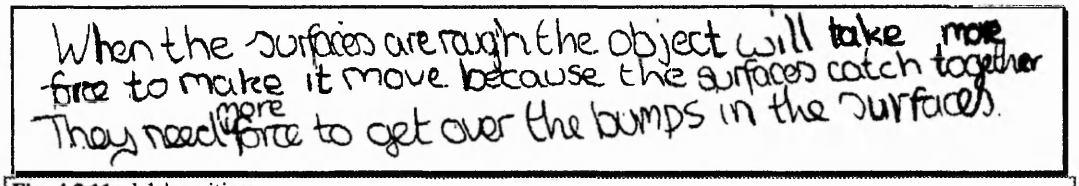


Fig. 4.2.11: Isla's writing.

Isla emphasised on the roughness of surfaces and wrote that "when the surfaces are rough the object will take more force to make it move because the surfaces "catch together" (see fig. 4.2.11). Thus, she added, "more force" is needed to "get over the bumps in the surfaces". The first statement seems to be generally true, but the second is a bit problematic, because when the object starts sliding, less pulling force is needed to pull it along, because usually sliding friction is less than the maximum static friction (cf. Chapter 2). This is something quite difficult to present and explain in a primary science classroom. Probably, the analogy of the jigsaw puzzle has created a misunderstanding in Isla's case. Unfortunately, analogies may create such problematic situations (cf. § 1.3.2).

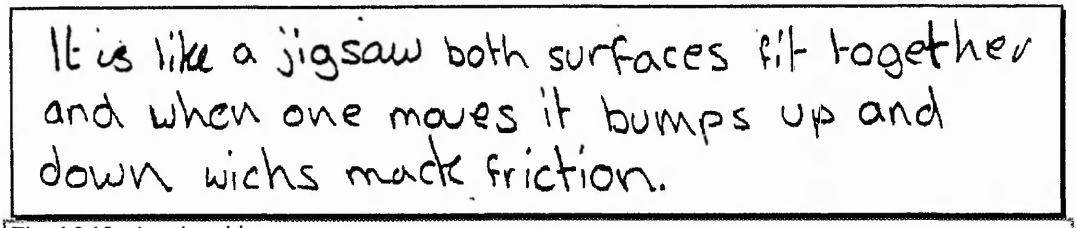


Fig. 4.2.12: Anna's writing.

Anna referred to the jigsaw puzzle analogy pointing out a metaphorical element of the analogy ("it is *like a* jigsaw"). She wrote that "both surfaces fit together and when one moves it bumps up and down which makes friction" (see fig. 4.2.12). Thus, she brought up the "bumping" of surfaces approach. She appears to be suggesting that friction is created when they move relatively to each other, probably bearing in mind the analogy with the moving fragment of the jigsaw, which was presented in class.

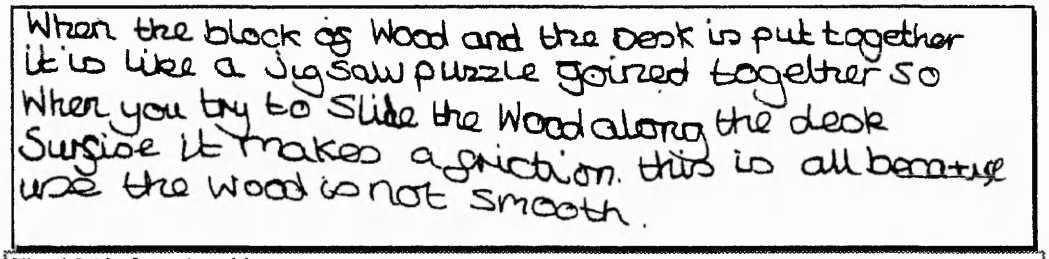


Fig. 4.2.13: Laura's writing.

Laura also uses the analogy of the jigsaw puzzle to describe the block and the table when they are put together ("it is *like a* jigsaw puzzle"). In her words, it is like they are "joined together" and because "the wood is not smooth", it "makes a friction" when you try to slide it "along the desk" (see fig. 4.2.13). She concludes that this is all because "the wood is not smooth". She seems to have accepted the "surface roughness" explanation of friction, although it is not clear whether she believes that there is friction even when the block of wood is not moving.

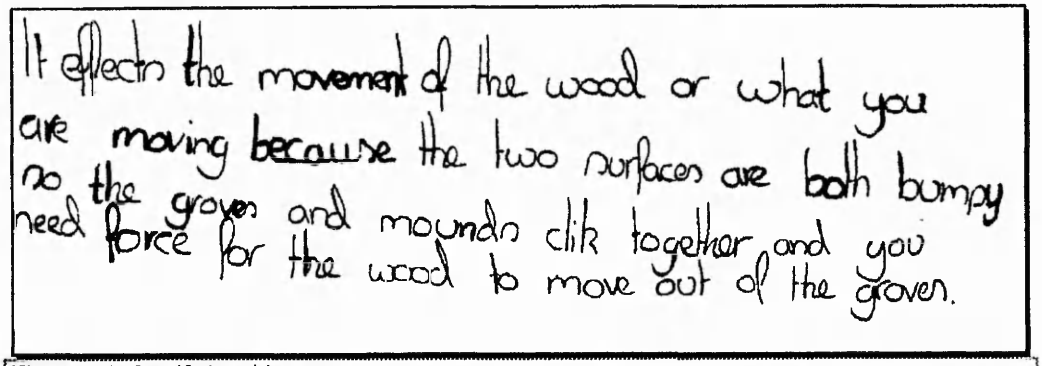


Fig. 4.2.14: Jennifer's writing.

Jennifer also refers to the bumpy surfaces which have "groves and mounds" which "click together and you need force for the wood to move out of the groves" (see fig 4.2.14). With this statement, she describes the interlocking of surfaces and she attempts, quite successfully, to explain the nature of sliding friction, possibly bearing in mind the jigsaw puzzle analogy. It is very interesting that she uses her own words to describe the nature of "bumpy surfaces".

4.3.0. Children's concept maps and respective comments

Some time and effort is required to introduce concept maps to a class or a group of children. Novak & Gowin (1984) have presented several strategies for introducing concept maps (cf. § 1..3.3.c). Some of these strategies were adopted in the study in England, where children initially constructed some concept maps on a subject they were interested in (e.g. football, music, etc.). They were told that they had to do their best to convey their messages to other people. In order to check the extent to which this was achieved, their concept maps would be commented and reproduced in text form by a classmate (see some examples in Appendix VIa). They seemed to enjoy this activity and when they had to write their commentaries for classmates' concept maps, they talked to each other and asked for some explanations. This seemed to improve their skills in drawing more clear concept maps.

After that, they did another concept map on "pressure", where they had to link some given terms (*pressure, force, weight, contact, area, spreading, bigger, smaller*), but they could always add their own, if they wanted to (see Appendix VIb). The third concept map they made was the one on friction, where the learners were given a list of terms related to friction (*friction, force, sliding, rubbing, surfaces, smooth, rough, tops and valleys, interlocking, slow down, not moving*) and they were expected to link them and express possible propositional relationships (cf. § 4.5). The concept maps on friction were constructed a week after the teaching intervention and the activity lasted for about fifteen minutes.

In this section, three of children's concept maps on friction are presented and some comments are given. The connections between words and the respective propositional links are reconstructed in the form of statements and interpreted. This aims to reveal some of children's conceptions on friction and frictional phenomena from a different point of view. Concept maps are also used as an additional source of

information in the analyses of the two cases of children that follow at the end of this chapter (cf. § 4.5).

4.3.1. (Jon)'s concept map

Hence, in (**Jon**)'s concept map, "friction" appears to be a starting point and it "is created when something is sliding and rubbing" over "another surface". The surfaces can be "rough" or "smooth". In the case they are "rough", they make things "slow down" or "stop", because of the "interlocking" of surfaces "on their peaks and valleys". Thus, he appears to be considering friction within its "surface roughness approximation". It seems rather difficult though, to interpret his propositional link between "friction" and "force". It seems to be "friction can't happen without a force" and he probably has in mind the experiments with the blocks of wood on the table that needed a "pulling force" to start sliding. Thus, in this concept map, he only seems to be considering "sliding friction". He does not refer to any situation where two surfaces are "not moving" relatively to each other.

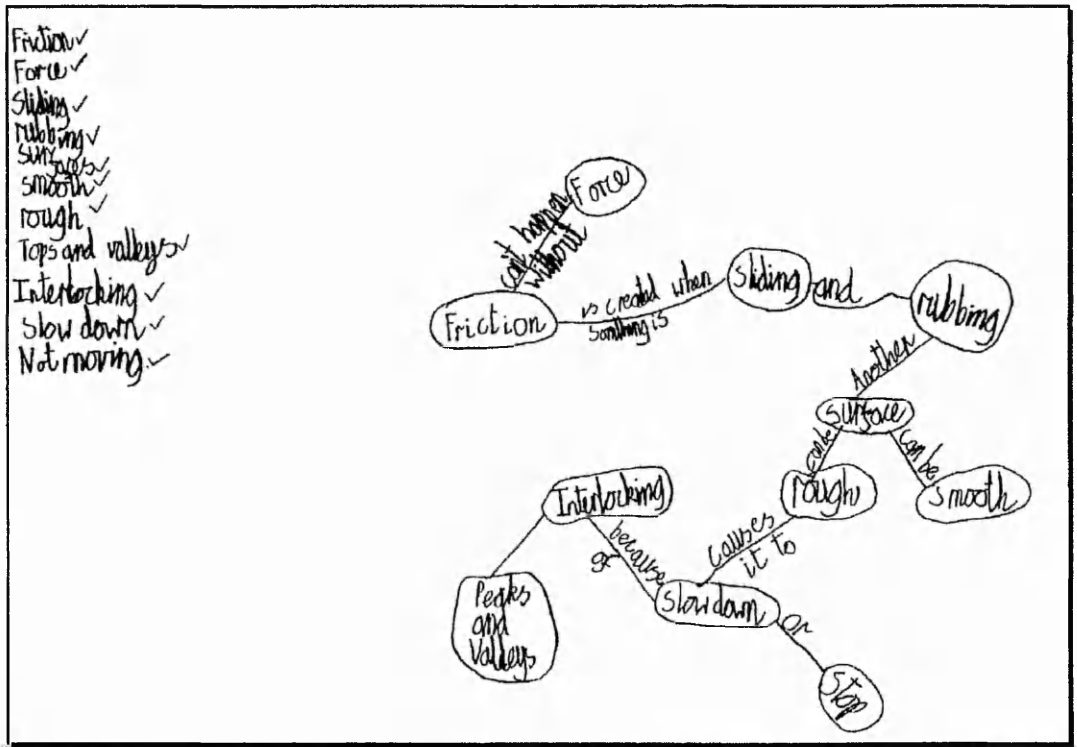


Fig. 4.3.1: (**Jon**)'s concept map on friction.

4.3.2. (Dav)'s concept map

Similarly, (**Dav**)'s concept map appears to have "friction" as a starting point. It seems to be explicitly stated though, that "friction is a force" and "it is made when" "rubbing surfaces", which can be "rough", "interlock" with their "tops and valleys" and they "are not moving". "Friction" is also "made when" "rubbing" occurs with surfaces that are "sliding" and it can cause their slow-down. His propositional link "can be", between "sliding" and "smooth", probably implies that "sliding surfaces can be smooth", or that "it is easier to slide things on smooth surfaces". Thus, (**Dav**) appears to be emphasising on "rubbing" surfaces that create friction, which seems to effect the slow-down or the motionless condition of bodies.

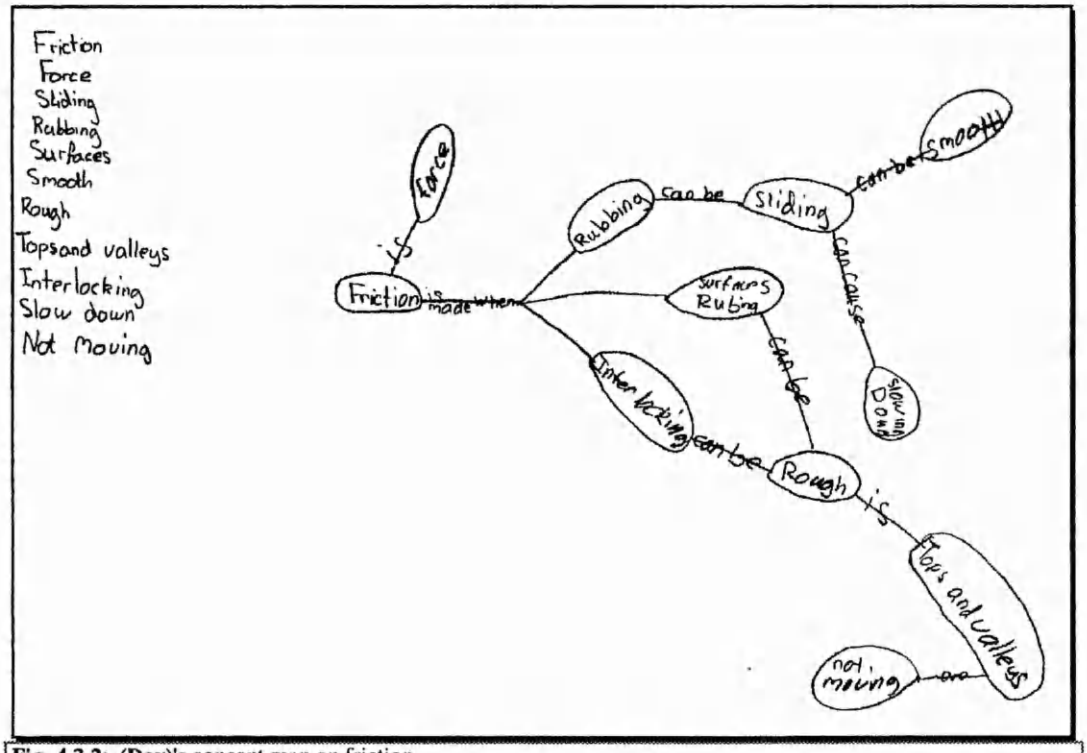


Fig. 4.3.2: (**Dav**)'s concept map on friction.

4.3.3. (Ph)'s concept map

Likewise, (**Ph**) appears to be indicating that "friction" is a "force". It seems that friction is "made" when the "tops and valleys of surfaces", "start interlocking" with each other and that makes them either "not move" or "slow down", when they are moving. Also, he seems to be suggesting that "friction is a force", which "makes rubbing when sliding on surfaces" and this appears to be "more" when they are "rough" and "less" when they are "smooth". Thus, he appears to be considering a "surface roughness approximation" of friction, which can be created from the interlocking of the irregularities of surfaces, or from the "rubbing" of "smooth" or "rough" surfaces, which effects the condition of stationary or moving objects.

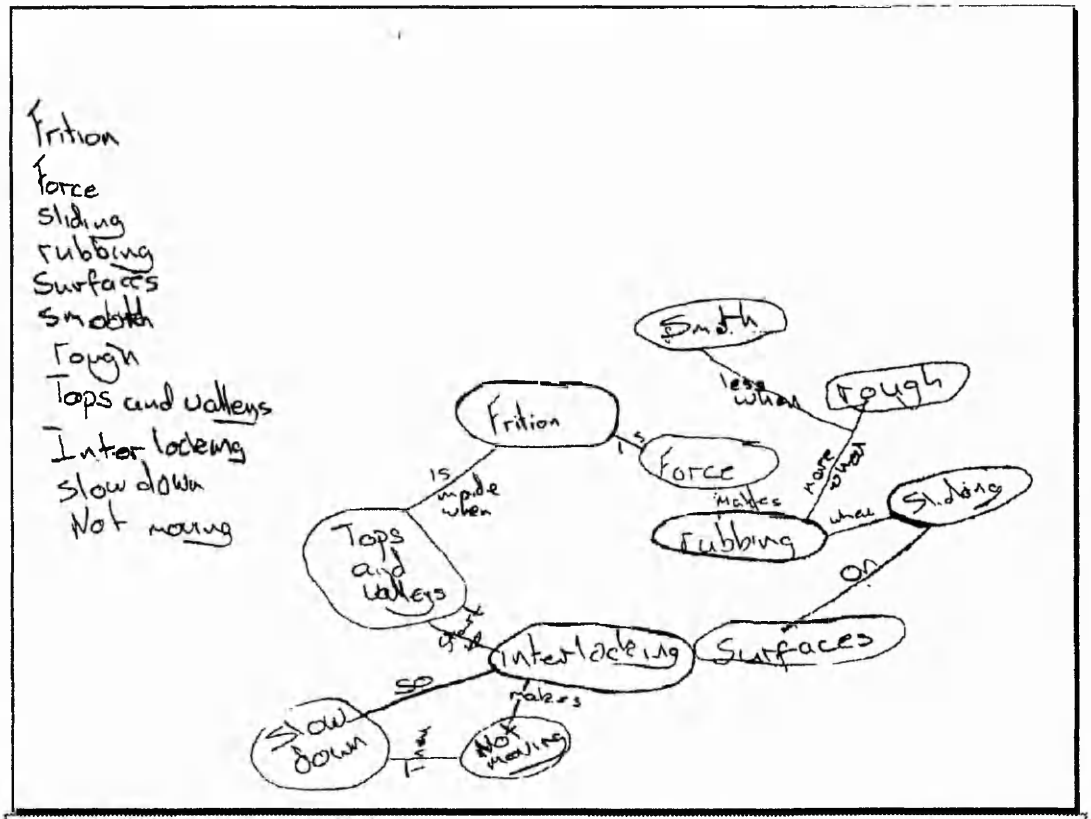


Fig. 4.3.3: (**Ph**)'s concept map on friction.

4.4.0. Post-Intervention Interview Analysis (England)

The purpose of this post-intervention interview analysis is to identify, present, and interpret groupings of conceptions and alternative conceptions, about friction and/or frictional phenomena, held by the children who participated in this study, after the teaching intervention. Each card is analysed separately, whereas the section is concluded with a discussion.

4.4.a. The card with 'the person walking along the street' instance

*Four children (**Ia, Pa, And, Ha**) appear to be considering friction through a notion of "grip" which is created because the surfaces of the shoes and the ground are "uneven" or "rough".*

(**Ia**) indicates that there is friction at the touching points of the shoes and the ground (006 & 008). He suggests that because the "shoes are rather rough" and "so is the surface of the road" or "the floor", they will grip (010) and they will be like the two pieces of the jigsaw puzzle which go into one another (011) as it was exposed during the teaching intervention.

006	**Int**	walking along the road.. is there any friction here.. / .. umm ..4.. yeah there's fiction there.. and friction there ..	[pointing under the shoes]
007	**Int**	what do you mean .. /	
008	**Ia**	er.. there's friction under the shoes of the person .. /	
009	**Int**	how do you think that friction is created there .. /.. under the shoes as you say..	
010	**Ia**	umm .. the shoes are rather rough .. so is the surface ... the road or the floor .. let's call it so ..	
010.5	**Int**	>> yeah ..	
011	**Ia**	.. and it's just like those two pieces of the jigsaw puzzle they go into one another .. and so they grip .. that's why he doesn't slip really .	

(**Pa**) seems to suggest that the shoes have "grip" which makes them "sort of stick on the road" and "that creates friction" (006). He explains that this "grip" is created because the surface of the road is "not exactly even", or roads are "a bit jagged" and so are the shoes (008). Thus, the uneven bits of the shoes "get hold off" the uneven bits of road and that's how they grip (008).

006	**Pa**	walking along the road .. is there any friction here .. /.. yeah.. the shoes would have to stick .. to the road .. so.. the shoes should have grip on it .. which will make them .. sort of stick on the road.. and that creates friction .. so they grip on the road ..
007	**Int**	umm hmm .. how do you think .. that grip is .. created .. /
008	**Pa**	er.. it's 'cos the roads .. are not exactly even .. they are a bit jagged and the shoes are .. like stick to it.. 'cos they can get hold off the uneven bits of the road .. which get into the uneven bits of the shoes .. 'cos they are also a bit jagged .. you see..

Similarly, (**And**) points out that there is "the grip" of the soles of the shoes on the road which creates friction (006) and that's why the person doesn't slip and looks as if there is "a sort of support" when she is walking (008). He suggests that the uneven surfaces of the shoes "fix together" with the roughness of the road and that creates friction and support "in way" (010)

006	**And**	walking along the road .. is there any friction here .. / .. er ... yeah .. there's the grip of the soles on the road .. that creates some friction ..
007	**Int**	yeah .. what happens with that grip .. / .. could you explain that a bit .. /
008	**And**	well .. if you didn't have any grip .. you would slip over the pavement and you wouldn't have the sort of support that is giving you .. when you are walking ..
009	**Int**	can you describe what you mean when you say .. grip .. /
010	**And**	umm .. the shoes are gripping on the ground .. 'cos .. the shoes have .. like uneven surfaces .. and they're kind of .. fixing together with the roughness of the road .. that creates friction and it's supporting you when you walk .. keeping you stable in a way ..

*Two children (**Ph, Is**) appear to be considering that friction between the surfaces of the shoes and the ground is created because they "catch up" on each other. In this way they appear to be describing, in their own words, the interlocking of surfaces.*

(**Ph**) points out that when the person is walking "his shoes are going to catch up the road" and as a result, they will grip, create friction and wear away (006). He suggests that the only contact areas are those of the shoes and the ground which are "uneven" or "rough" and that's the only place where friction is created (007), because the surfaces "really catch on each other" (009).

006	**Ph**	walking along the road.. is there any friction here.. / .. umm .. let me see.. yes.. on the road .. 'cos when he is walking his shoes are going to catch up the road .. create friction wear away .. that's the grip of the shoes .. something like that...
006.5	**Int**	**>>** umm hmm ..
007	**Ph**	.. that's about all the friction I can see in there.. that's the only contact areas..
008	**Int**	I see .. how do you think friction is created there .. /
009	**Ph**	rubbing.. 'cos the rough surface of the road.. and the .. uneven surface of the shoes .. so they really catch on each other.. and they create friction ..

(**Is**) seems to be thinking in a similar way, when he says that the person puts "his feet" or "his shoes" on the pavement and friction is created because of the uneven surfaces that "catch on each other" (008 & 010). He suggests that this is happening because the surfaces have "little hills and valleys" and they "just go into" each other (012).

008	**Is**	well .. when he puts his feet down .. then there's friction ..	
009	**Int**	umm hmm .. could you explain that a bit please .. /	
010	**Is**	umm .. when he puts his feet on the pavement .. well his shoes I mean really .. the surfaces are uneven like .. it's the shoes and the pavement are uneven surfaces .. and they catch on each other .. that creates friction ..	
011	**Int**	what do you mean when you say that .. they catch on each other .. /	
012	**Is**	umm .. well .. it's uneven surfaces .. like .. they have little hills and valleys .. like my shoes here .. and they just go into the hills and valleys of the pavement .. or the road .. something like that happens ..	[she is pointing under her shoes]

*Three children (**Da, Jo, An**) appear to be holding a conception that friction, between the surfaces of the shoes and the ground, "depends on" a possible "dragging", "scrapping" or "sliding" of the shoes on the ground. In this sense, friction seems to be associated with the "rubbing" of the shoes and the ground. Thus, if the person is not dragging the shoes on the ground, there is "very little" friction (**Da, Jo**) or "not really any friction" (**An**).*

(**Da**) seems to be pointing out that there is "a little bit of friction" when the person walks and that it will be more if the person is "dragging" his/her "feet" on the ground because there will be more rubbing in that case (006 & 010), making it "a lot more difficult to walk" (010). On the other hand, he suggests that if the person is walking "normally" there isn't much contact with the ground and so there is "a little bit of friction created", just to keep the person going (008).

006	**Da**	walking along the road .. is there any friction here .. /.. yeah .. there's a little bit of friction .. it would be more friction if you're dragging your feet on the ground .. 'cos they rub more you see ..
007	**Int**	yeah .. but what happens when you don't drag your feet .. / .. when you just walk normally .. /
008	**Da**	well there's not really much contact in this case .. or there is some but not much .. there is just a little bit of friction created .. to keep you going I suppose ..
009	**Int**	what happens when you are dragging your feet on the ground then .. /
010	**Da**	er .. when you are dragging your feet they hardly get off the ground .. so they really rub more and that creates friction .. that's why .. when I am dragging my feet .. it makes it a lot more difficult to walk ..

In a similar way of thinking, (**An**) suggests that friction on the shoes depends on whether the person is "scrapping" his/her feet or not (006 & 008). Thus he describes

the process of walking as lifting the feet up and put them back down and push off again and suggests that "you don't make any friction" in that case, because there is no rubbing (008) or not much grip (014) with the floor. He seems to claim though, that if the person is running, then "grip" is needed to "pin" him/her down (010) and that can create friction, which happens when the shoes rub and "sort of go into the surface of the ground" (012).

006	**An**	walking along the road .. is there any friction here .. / .. umm .. well .. it depends ..
007	**Int**	on what .. /
008	**An**	well .. if you're scrapping your feet or not .. 'cos if you are lifting your feet .. say when you put them back down and you push off again .. you don't make any friction .. 'cos you are not .. umm running along the floor ..
009	**Int**	what would happen if you run then .. /
010	**An**	well if you run .. you need some sort of grip .. to .. say .. to pin you down on the floor ..
011	**Int**	how do you think that friction is created there .. /
012	**An**	umm .. the shoes .. rub .. sort of .. say they go into the roughness of the surface of the ground .. and so they grip a bit ..
013	**Int**	I see .. anything else you would like to add here .. /
014	**An**	no .. umm .. there's not really friction when we walk .. / .. umm .. 'cos you don't really have to grip much .. it's not like when you run ... that's .. that's what I think .. /

*Three children (**Ia, Pa, Is**) refer to a special case of walking on ice and suggest that "there is not much friction" or "no friction at all" and they also express their reasoning for the phenomenon.*

(**Pa**) points out that the gripping of the shoes on the ground is like "sticking them on the road", which is something different than walking on ice (010), where "we can't really walk" since it is "slippery", shoes don't grip or "there is no friction" there (012).

009	**Int**	yeah.. do you think that .. this griping .. helps us to walk.. /
010	**Pa**	yeah .. I think so .. 'cos it's like sticking on the road.. a bit .. so we don't slip and fall down.. just like we do on ice..
011	**Int**	what happens on ice .. /
012	**Pa**	er.. we can't walk really.. we slip on it and we fall down.. 'cos our shoes don't grip .. it's slippery.. so there's no friction really there ...

(**Is**) seems to be quite sure that the person wouldn't be able to walk without friction (014). She suggests that the person "can't really walk" on ice and she will slip because it is "sort of greasy" and the shoes won't grip (016).

013	**Int**	all right .. anything else you would like to add here .. /
014	**Is**	umm .. he wouldn't really walk without friction .. as you can't really walk on ice .. you'll slip ..

015 **Int** umm hmm .. why do you think that you'll slip when you try to walk on ice .. /
016 **Is** umm .. 'cos it's sort of greasy .. your shoes can't really grip on it .. so there's not much friction to keep you on your feet and .. and you'll just slip and fall down ..

Interview Card	*Groupings of conceptions and alternative conceptions*	*NoR*
	• **The "uneven", "rough" or "jagged" surfaces of the shoes and the ground "grip" and create friction when the person is walking.**	*4*
	• **The rough surfaces of the shoes and the ground "catch up" creating friction.**	*2*
	• **If the person is "dragging", "scrapping" or "sliding" the shoes on the surface of the ground, they rub and create friction, otherwise there is "very little" or "no friction".**	*3*
	• **There is "very little" or "no friction when a person is walking on ice because it is "slippery" or "sort of greasy".**	*3*

Table 4.4.1: A synopsis of the groupings of conceptions and alternative conceptions from the analysis of the "person walking along the street" instance with respective numbers of children's responses (*NoR*).

4.4.b. The card with 'the book on the tilted table' instance

*Five children (**Da, Ia, And, Is, Ha**) appear to be holding a conception that friction between the surface of the book and the surface of the tilted table depends on the nature of the surfaces or on their "roughness" and they express their descriptions and reasoning for the creation of this friction.*

(**Ia**) suggests that the surfaces of the book and the table "grip one into the other". He demonstrates that by "gripping" two of his fingers and points out that "it all depends on the surfaces" (028). He attempts to give an explanation by suggesting that if the surfaces are bit "jagged" or like the "grips on a tyre", they "sort of stick together" or "interlock with each other" (030) and this is what happening in the depicted instance which resembles with the two pieces of the jigsaw puzzle when they "fix in together" (032).

028 **Ia** .. umm .. they grip one into the other.. like that .. and so the book manages to hold itself up there .. it all depends on the surfaces .. you see .. [demonstrates it with his fingers]
029 **Int** depends on the surfaces .. you say .. what do you mean .. /
030 **Ia** if the surface is jagged .. or like the grips on a tyre.. a bit like that.. and the two surfaces come together.. they get a close grip.. and they just .. sort of stick together.. or.. as we said .. they.. inter.. interlock with each other ..
031 **Int** I see .. is that what happens in this situation then .. /
032 **Ia** yeah 'cos both of the surfaces are jagged here.. and they .. just like the jigsaw .. they just fix in together.. on both sides they just fix in together.. and that stops it there..

In a similar way of thinking (**And**) suggests that "the kind of grip depends on the surfaces" which "sort of weld together" (016). Thus he points out that the book on a table with plastic laminate would "slide straight down" because there wouldn't be much friction and suggests that things would be different if the book had a "hard cover" (018). In an attempt to describe the phenomenon further, he refers to the analogy with the jigsaw puzzle and says that there are "tiny bits of stuff hanging out of each surface" which "catch on each other" and that's how two surfaces "weld together" (021).

016	**And**	well the kind of grip depends on the surfaces that are touching each other .. er .. the surface that the book and the table is made of .. they sort of weld together ... and the book won't slide down as easy ..	
017	**Int**	umm hmm .. I see ..	
018	**And**	er .. say if it was a work book and a table like that one .. with plastic laminate on it .. it would slide straight down .. 'cos there wouldn't be much friction to keep it there ..	[pointing to a table near by]
018.5	**Int**	**>>** umm hmm ..	
019	**And**	.. but say if it was one of the big books .. like a hard cover or something .. and it was on a modern table .. then friction would grip it .. weld them together .. sort of .. and the book would stay still ..	
020	**Int**	I see .. how do you think that the two surfaces weld together as .. / .. as you said it ..	
021	**And**	well it's a bit like the jigsaw puzzle .. two pieces of it coming together .. there are .. sort of .. tinny bits of stuff hanging out of each surface .. 'cos all surfaces are uneven .. and so .. they catch on each other ..	

(**Is**) indicates that the surfaces of the book and the table are "uneven" (018) and they "sort of rub together" (020) because they are "a bit bumpy" and "rough", so they "get caught with each other" creating friction (022).

018	**Is**	we lift the table up a little bit from one of the sides .. the book does not slide down .. do you think friction is keeping it there .. / .. umm ..4.. yeah .. it is .. 'cos the surfaces are uneven .. and you'd have to lift the table a bit more up .. to make it go down .. slide down the table ..	
019	**Int**	the surfaces are uneven .. you say .. what do you mean .. /	
020	**Is**	umm .. well it's .. the surfaces .. are uneven .. I mean the book and the table .. and they sort of rub together ..	
021	**Int**	yeah .. could you explain that a bit please ..	
022	**Is**	umm .. it's 'cos the surfaces are uneven .. say the cover of the book say a big hardback book .. that would be a bit bumpy .. you can feel it really .. and if you put it on the .. on the wooden table .. that is also rough ... so you put it there .. and the surfaces rub with each other .. they get caught together .. and create friction ..	[pointing at the inclined table]

*Two children (**Ph, Pa**) appear to be considering that friction and gravity are closely related and somehow assist each other in keeping the book stationary on the tilted table.*

(**Ph**) appears to be analysing the force of gravity in two components, one pulling downwards and one pulling along the surface of the table (015). He appears to be suggesting that friction and gravity are trying to keep the book down steady on the table and there is only the component of gravity pulling it down along the surface of the table, to slide it potentially (016). Then he points out that friction is created because the surfaces are not smooth and they "catch and hold there" (018) or they will "go into one another" just like the two pieces of the jigsaw puzzle (020).

015	**Ph**	we lift the table up a little bit from one of the sides .. the book does not slide down .. do you think that friction is keeping it there .. / .. err.. there's gravity pulling the book this way.. and there's a bit of gravity pulling it that way .. 'cos the table is in the middle .. you see ..	[pointing downwards first and then along the surface of the inclined table]
015.5	**Int**	**>>** umm hmm ..	
016	**Ph**	.. and there's friction there .. friction is holding it there .. so it has no chance to go down this way.. it has to stay where it is .. 'cos friction is trying to keep it down .. gravity is trying to keep it down .. so there's only one force pulling it that way and two forces pulling it that way..	[pointing along the surface of contact of the book and the table] [pointing first along the surface of the table and then downwards]
017	**Int**	umm hmm .. I see .. how do you think that friction is created there .. /	
018	**Ph**	well .. same with the shoes .. rubbing .. like.. they are not smooth surfaces .. and they will catch and hold there .. they've got to catch 'cos they .. you can't really have smooth surfaces ..	
019	**Int**	how do you think that this .. catching of surfaces .. happens .. /	
020	**Ph**	well .. they go into one another just like the pieces of the jigsaw puzzle we saw the other day.. er.. when the book is steady .. say like here.. it interlocks with the surface of the table.. that's how friction is created..	

(**Pa**) appears to be considering that there is friction between the surfaces of the book and the table because they are touching each other just like two hands which are put together and they are "like stuck" (017). He suggests though, that gravity "helps the book stay on the table by pulling it downwards", "sticking" it on the table (018 & 022) together with friction which is created due to the "bits and pieces" "hanging out of" the surfaces which "just get into one another" (020). Hence, he appears to be considering gravity as necessary condition for two surfaces to be in contact and create friction.

017	**Pa**	we lift the table up a little bit from one of the sides .. the book does not slide down .. do you think friction is keeping it there .. / .. umm .. yeah there is friction .. 'cos the table surface and the book surface are touching each other like .. as you put your hands together you can't exactly slide them .. 'cos it's like stuck ..
017.5	**Int**	**>>** umm hmm ..
018	**Pa**	.. but I think that also the gravity helps the book stay on the table .. by pulling it downwards ..
019	**Int**	yeah ..
020	**Pa**	so .. I think it's the surface of the book and the surface of the table .. sticking to each other .. 'cos bits and pieces are hanging out of them ... and they just get into one another ... err.. but also gravity that is coming down .. makes the book stick to the table even more ..

021 **Int** do you mean that gravity is also another force .. apart from friction .. that helps the book stay there .. /
022 **Pa** yeah .. exactly that..

*Two children (**Jo, An**) appear to be differentiating between "friction" and "grip" suggesting that there is "friction" when an object, like the book on the tilted table, is "sliding" or "rubbing" on a surface and there is "grip" when the object doesn't move as in the case that the book which remains stationary on the table. It could be claimed that, in their terms, they appear to be holding a conception about the distinction between sliding and static friction, or they view "grip" as a characteristic of surfaces that are stationary to each other and "friction" as a characteristic of surfaces that are in relative motion with each other..*

Thus, (**Jo**) seems to differentiate between "friction" and "grip" by pointing out that "if we consider friction as grip" then there is "friction" keeping the book on the tilted table (017) because it is "gripping", which means that the "roughness of the surfaces" (021) "gets into one another, just like the two pieces of the jigsaw puzzle" (023). She claims though, that "grip is a kind of friction" but she seems that she would feel more comfortable to use the term friction in the case that "the book slides down the table" because it "would be rubbing then". Thus, it could be claimed that she views the existence of "friction" in the case that there is relevant movement between two surfaces ("rubbing", 025).

017 **Jo** we lift the table up a little bit from one of the sides .. the book does not slide down .. do you think friction is keeping it there .. / .. umm .. well if we consider friction as a grip .. then there **is** friction keeping the book there ..
018 **Int** what do you mean .. /
019 **Jo** umm .. the book is **gripping** on the table .. that's the only way that it can stay there .. as far as I can think of ..
020 **Int** the book is gripping .. you say .. can you explain that a bit .. /
021 **Jo** yeah .. it has to do with the roughness of the surfaces .. 'cos both of the surfaces are rough here .. I mean the book and the table ..
022 **Int** what happens then .. /
023 **Jo** they get into one another .. it's just like the two pieces of the jigsaw .. so they grip .. in a way .. and that's why the book stays there ..
024 **Int** do you think that grip is different from friction .. /
025 **Jo** umm .. I think grip is a kind of friction .. but I would say there would be definitely friction when the book slides down the table .. 'cos that would be rubbing then .. wouldn't it .. /

Likewise, (**An**) seems to be pointing out with emphasis that "grip" is keeping the book steady on the tilted table with gravity "helping" it (016, 018 & 020). He

suggests that there is "no friction" in that case, because with friction "you can make heat when you rub things" (018) or the book will be "making friction" when the table is tilted a bit more and it starts sliding (022).

016	**An**	we lift the table up a little bit from one of the sides .. the book does not slide down .. do you think friction is keeping it there .. / .. umm .. grip is .. I don't think friction is though .. er.. I don't think friction is keeping it there ..
017	**Int**	umm .. is there a difference between grip and friction .. /
018	**An**	well .. yeah .. with friction .. you can .. what .. just one of the reasons .. you can make heat with friction when you rub things .. but that's not anything I see with this ... but grip is actually keeping it *(the book)* there .. I think that gravity is helping it .. and stuff .. but there's no friction on that thing ..
019	**Int**	what is happening at the touching surface of the book and the table .. /
020	**An**	it's **gripping** .. /
020.5	**Int**	**>>** yeah ..
021	**An**	'cos .. if you slant it more it will start sliding .. then it will be making friction ..

*Three children (**Ia, Da, Ha**) appear to be suggesting that there will be less friction when the table is lifted a bit higher and the book starts sliding. They also express their explanations for this.*

(**Ia**) points out that the book will start sliding if the table is lifted a bit higher or if it is gently pushed, but he suggests that friction "wouldn't be able to hold" it from sliding down (036) because it "is not really strong enough" (040). Thus, if the table is lifted higher, gravity will be the only force pulling the book down, along its the surface (038).

033	**Int**	what would happen if someone lifted the table a bit more up .. / .. or if someone say gave it a gentle push .. /	
034	**Ia**	I think it would slide .. it would slide if you lifted the table up.. also if you pushed it a bit ..	
035	**Int**	do you think there would be any friction then .. /	
036	**Ia**	umm .. there would be .. yeah.. a little bit .. but it wouldn't be able to hold the book from sliding down ..	
037	**Int**	what do you mean .. /	
038	**Ia**	er.. that force there.. is pulling it more down .. also gravity is pulling it more down .. actually gravity would be the only force pulling it down .. if the table wasn't in the way .. you know.. *(laugh)*..	[pointing along the inclined surface of the table]
039	**Int**	yes.. I see ..	
040	**Ia**	so .. fiction is not really strong enough to keep it there.. when you push it .. or lift the table a bit more up ..	

(**Ha**) appears to be suggesting that there is a "little bit of friction" when the book is sliding along the surface of the table because "it doesn't go down very fast" or "there is something holding it back" (022).

021	**Int**	do you think there is any friction when the book is sliding down the table .. / .. when we lift it a bit more up .. as you say ..

022 **Ha** umm .. well there could be a little bit of friction when it is sliding .. the book .. it could cause a tiny bit of friction .. it doesn't go down very fast .. you see .. so there is something holding it back .. that could be a slight friction ..

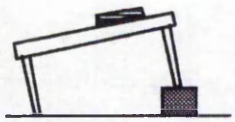
Interview Card	Groupings of conceptions and alternative conceptions	NoR
	• **Friction in the interface of the book and the table depends on the "roughness" of surfaces which are "jagged" "bumpy" or "uneven" and they "grip", "interlock", "fix" or even "weld together".**	*5*
	• **Gravity "helps" friction in keeping the book steady on the surface of the tilted table by "sticking" it there in a way.**	*2*
	• **There is "grip" when the book remains stationary on the tilted table, but there is "friction" when it starts sliding.**	*2*
	• **There is less friction when the book is sliding along the surface of the tilted table because "gravity is pulling it more downwards" or because it "doesn't go down very fast".**	*3*

Table 4.4.2: A synopsis of the groupings of conceptions and alternative conceptions from the analysis of the "book on the tilted table" instance with respective numbers of children's responses (*NoR*).

4.4.c. The card with 'the block of wood on the table' instance

*Seven children (**Ia, Pa, Da, And, Is, Ha, Ph**) appear to be considering that there is friction in the interface of the wooden block and the table, which "depends on" the "roughness" of the surfaces in contact. They point out that the surfaces "grip", "get into each other", "fix together", "catch together" or "rub", creating friction, much like the two pieces of the jigsaw puzzle (**Is, Ha**). Furthermore, most of the children (**Pa, Da, And, Is, Ha**) appear to be suggesting that, apart from friction, another reason for the motionless condition of the block seems to be the fact that "there is not enough weight" or "not enough force" to pull it along the surface of the table.*

(**Ia**) suggests that friction "depends on the surfaces" (044) and indicates that if the surface of the table is rough, the wooden block will not slide along the table even if the weights are pulling it. But, if more weights are added in the tray, then the book will slide (046). Thus, if the surface of the table was not rough then the block would not "grip as much" and it would "slide easier", "probably with less weight" (048).

044 **Ia** there's some weight in the tray which is under the pulley at the end of the string .. but the block of wood does not slide on the table .. do you think friction keeps it there .. / .. umm ..4.. it depends on the surface again ..

045 **Int** what do you mean .. /

046	**Ia**	well .. if the surface of the table is rough .. it wouldn't go along.. even if that weight is pulling it .. but if we put more weight .. even on this rough surface it would go.. it would pull it along..	
047	**Int**	what would happen if the surface of the table wasn't rough .. /	
048	**Ia**	er.. the block of wood wouldn't grip as much.. friction would be less .. so it would slide easier .. even.. well .. probably with less weight there ..	

(**Pa**) appears to be considering the roughness of the surfaces, but at the same time he indicates that "there is more weight" on the piece of wood than in the tray (035). Thus, there is not enough weight to pull the block along the surface of the table and "get it away from friction" (036). He seems to suggest that, according to the investigation which was conducted during the teaching intervention (cf. § 4.2.5), approximately one fourth of the weight of the block is needed to slide it on the table (038).

035	**Pa**	there is some weight in the tray which is under the pulley at the end of the string .. but the block of wood does not slide on the table .. do you think friction keeps it there .. / .. well it's the roughness of the surfaces of the block of wood and the table .. but also .. there's more weight on that piece of wood .. than it is in that tray...	
035.5	**Int**	>> umm hmm ...	
036	**Pa**	.. so .. there's not enough weight to pull it .. to get away from the friction ..	
037	**Int**	yeah .. I see ..	
038	**Pa**	so .. even if we have rough surfaces which cause some friction .. it will move .. if .. if .. we put some more weight in the tray .. say .. about one fourth of the weight of that wood .. as we found out the other day ..	

(**And**) appears to be regarding that the surfaces "grip together" because "the little tinny bits that are hanging off the surfaces get into each other" (025) or they "fix together" (027) and that "causes friction" (025). He also mentions that there is not "much weight to pull it *(the block)* along" and suggests that "one fourth of the weight of the block" is needed for the block to start sliding, if there is no sandpaper on the table (028).

025	**And**	there is some weight in the tray which is under the pulley at the end of the string .. but the block of wood does not slide down .. do you think friction keeps it there .. / .. er.. it's a bit like the previous one .. the surfaces grip together .. 'cos the little tinny bits that are hanging off the surfaces get into each other .. and that causes friction ..	
026	**Int**	there is some weight pulling the block of wood that way .. why do you think that it doesn't slide .. /	[pointing to the right]
027	**And**	well .. because of the grip of the surfaces ... they fix together .. sort of .. you see the wooden table and that piece of wood .. I mean .. and that creates friction ..	
027.5	**Int**	>> umm hmm ..	
028	**And**	.. but obviously there isn't much weight to pull it *(the block)* along .. if we want it to slide we must put some more weight there .. err .. and if we don't have sandpaper on the table .. we'll need about one fourth of the weight of the block .. that's what we found out last week ..	[pointing at the tray]

Likewise, (**Ha**) recognises that the surfaces of the block and the table are "rough" and the table becomes even rougher" when it is covered with sandpaper (028). Hence, the surfaces are "quite bumpy" and they "get caught on their bumps" or they "fit together like a jigsaw puzzle" (029). She also mentions that "the block of wood is too heavy for the weights to pull it along the table" and suggests that if the table was covered with sandpaper, "a lot more weight in the tray" would be needed for the block to start sliding (030).

028	**Ha**	umm .. it's the table and the block of wood that have rough surfaces .. and the table becomes even rougher when we put sandpaper on it .. like we did the some days ago ..
028.5	**Int**	>> yeah ..
029	**Ha**	.. so .. the block of wood is too heavy for the weights to pull it along the table .. but also .. because it hasn't got a smooth surface .. the same with the table .. they are both quite bumpy and they get caught with each other .. they get caught on their bumps .. they fit in together like a jigsaw ..
029.5	**Int**	>> umm hmm ..
030	**Ha**	.. and that creates friction which actually stops it from moving .. as well as it could move .. and when you have sandpaper .. you need to put a lot more weight in that tray for that block of wood to start sliding ..

(**Ph**) indicates that there are four forces on the block, the weight pulling it down [along the surface of the table], gravity pulling it down onto the table, the table supporting it and friction which is created because the wooden block is "catching onto the table" (026). He suggests that the bits of wood, that are "hanging off" the surfaces of the block and the table, create friction, which would be less if the surface of the table was covered with plastic laminate because "there are hardly any crannies" on the surface in that case (030). He discusses it further by giving an example about the friction created "on the wooden table and the wooden block". He suggests that it looks like two hands rubbing together, creating "a little" dirt. They catch friction and they "get warm" (032).

026	**Ph**	er ..4.. the weight is pulling the block down.. if there was more weight.. there would be more force pulling it down .. gravity is pulling it down and onto the table.. we've got the table supporting it and we've got the wooden block catching onto the table creating friction..
027	**Int**	how do you think friction is created there.. /
028	**Ph**	on the wooden block.. /
029	**Int**	yeah ..
030	**Ph**	well .. it's not a smooth surface .. there are bits of wood hanging off everywhere.. same with the table.. if it is made .. say out of wood ... 'cos if it was made of plastic laminate like this one here .. the block will slide easily .. 'cos there'll be less friction .. 'cos there are hardly any crannies on this surface .. so there wouldn't be as much friction ..

031	**Int**	what happens with the wooden table then .. /
032	**Ph**	the wooden table is more .. it is not very smooth .. so.. they are catching with each other .. on the wooden table and the wooden block .. so that creates friction .. like if you are rubbing your hands together.. you've got a little dirt in your hands .. so they catch friction .. and if you do it long enough .. your hands will get warm .. 'cos of the force they are creating against each other ..

*Two children (**Jo, An**) appear to be differentiating between "friction" and "grip" suggesting that "grip" happens when the block is pulled but it doesn't slide and "friction" is created when the two surfaces of the block and the table move relatively to each other and they "rub" in a way.*

(**Jo**) appears to be considering that the block is not sliding because there is not enough weight in the tray and "there is some gripping as well" (031). This is due to the roughness of the surfaces (033), from the "little hills and valleys coming out of" them, gripping with each other (034). Hence, she suggests that there is some friction when the block of wood is sliding because it "is rubbing on the table", but "there is not much grip though" (038 & 040). She appears to be differentiating "friction" from "grip" by saying that "there is grip when the block is stationary", but there is "friction when the block is sliding" because in that case it is "rubbing on the table" (044).

031	**Jo**	umm .. well .. there isn't enough weight in that tray to pull the block of wood along the table .. and there is some gripping as well ..
032	**Int**	what do you mean when you say .. gripping .. in this situation .. /
033	**Jo**	well .. it has to do with the roughness of the surfaces again ..
033.5	**Int**	**>>** umm hmm ..
034	**Jo**	.. 'cos the piece of wood is rough .. and the wooden table is also rough .. er.. there are some little hills and valleys coming out of each of these surfaces .. and so they are gripping .. and that's why the block of wood stays there .. and does not slide along the table ..
035	**Int**	what happens if we put some more weight in the tray.. /
036	**Jo**	the block of wood will start sliding ..
037	**Int**	is there any friction then .. /
038	**Jo**	yeah .. there is 'cos the block of wood is rubbing on the table .. 'cos it's sliding .. and that creates friction .. er.. it doesn't grip much though ..
039	**Int**	what do you mean .. /
040	**Jo**	well .. there is some friction but not much grip ..
041	**Int**	are these two different .. /
042	**Jo**	yeah .. I think so ..
043	**Int**	in what way .. /
044	**Jo**	there's grip when the block of wood is .. stationary .. but then when it is sliding there is friction .. 'cos then it is rubbing on the table .. that's how it happens ..

(**An**) seems to be suggesting that the block is not sliding because there is not "enough force" from the weight in the tray (034) and there is "some grip" (035) "between the touching surfaces of the table and the block of wood" (037). He appears to be

differentiating between "friction" and "grip" by saying that when the block is pulled without sliding then that can be called "grip", but "friction" is when "you move two surfaces together, one over the other" and they also cause some heat (040).

034	**An**	there is some weight in the tray which is under the pulley at the end of the string .. but the block of wood does not slide on the table .. do you think friction keeps it there .. / .. umm .. there isn't enough force from that weight in the tray .. trying to pull it *(the block of wood)* along the table ..
034.5	**Int**	>> yeah ..
035	**An**	.. umm .. and I suppose there is some grip .. as well ..
036	**Int**	grip .. / .. where do you think that it exists .. /
037	**An**	umm .. between the touching surfaces of the table and the block of wood ..
038	**Int**	yeah .. do you think that this grip is related to friction .. /
039	**An**	well .. I am not really sure if you can call it friction if you just pull it .. say if you just put a block of wood on the table and just pull it .. without doing anything to it .. without any sliding .. that's grip really .. I don't think you can call that grip .. friction .. er..
039.5	**Int**	>> umm hmm ..
040	**An**	.. so .. I am not really sure .. 'cos the main thing of friction is .. I think .. when you move two surfaces together .. one over the other.. also causing some sort of heat and stuff ..

*Five children (**Ia, Ha, Pa, And, Is**) appear to be suggesting that "part o friction" or "a little bit" of it is "still" there when the block starts sliding and they attempt to explain their view mostly within "a surface roughness theory" of friction. Two of these children (**An, Is**) point out that there would be "very little" or "no friction" if the block was slid on ice.*

(**Ia**) points out that "friction can't take it" when more weight is put in the tray and the block starts sliding (049) and suggests that "a bit of friction is still there" or "part of it is there" (051). He describes friction between the sliding surfaces of the block and the table as "two pieces of a jigsaw puzzle" that "go together" and fit, but when one is moved over the other, some bits are "knocked away", since "all these ups and downs change place all the time" (053) and they "hit" or "strike over each other", making "some friction" (055).

049	**Int**	do you think that friction is still there .. / .. when the block will start sliding ..
050	**Ia**	yeah .. if there's a lot.. if there's more weight .. then friction can't take it and the book would slide ..
050.5	**Int**	>> umm hmm ..
051	**Ia**	.. now.. I think.. some .. a bit of friction is still there .. when it slides.. er ..4.. part of it is there .. 'cos the block of wood is going along .. it's moving ..
052	**Int**	how do you think that part of friction is there .. when the block of wood is sliding .. /
053	**Ia**	well .. you know .. when you showed those two pieces of the jigsaw puzzle... when those two bits go together.. they fit.. but if you try to move one over the other .. it knocks bits of the jigsaw away .. all these ups and downs change place all the time ..

054 **Int** yeah.. what happens with the sliding block of wood then ..
055 **Ia** well .. the ups and downs of the surfaces .. hit .. strike over each other .. that makes some friction .. even when it's sliding ..

(**Ha**) suggests that there is "still some friction" when the block is sliding because it doesn't go very fast (032) and the "bumps" of the surfaces are "still there" and "they go over one another" (034).

031 **Int** do you think there is any friction when the block of wood is sliding on the table .. /
032 **Ha** umm .. yeah .. there is still some friction .. 'cos it doesn't go very fast .. does it.. /
033 **Int** well .. yeah .. it doesn't go very fast ..
034 **Ha** so .. I reckon there is still some friction when it is sliding .. 'cos the bumps are still there .. and they go over one another ..4..

(**Is**) points out that friction "gets weak" when more weight is put in the tray and it starts sliding on the table (037), but there is still "a bit of friction" because there are still "bits of wood catching with each other" and "it goes a bit slowly" (039). She also mentions that the block would slide very fast "if there was no friction", just like in the case that it is slid on ice (041).

037 **Is** .. but if you put more force .. more weights in that tray .. it will move .. it will start sliding .. 'cos friction gets weak ..
038 **Int** friction gets weak .. what do you mean .. /
039 **Is** well .. there's still a bit of friction .. but not as much as .. when it *(block of wood)* was not moving .. 'cos if it's moving there's still bits of wood catching with each other .. that's why it goes a bit slowly .. till it reaches the end of the table ..
040 **Int** umm hmm .. I see .. anything else you would like to add here .. /
041 **Int** yeah .. when it slides .. if there was no friction .. it would slide really fast .. just like on ice .. that's all ..

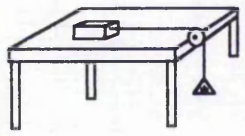
Interview Card	*Groupings of conceptions and alternative conceptions*	*NoR*
	• **Friction depends on the roughness of the surfaces in contact because they "grip", "fix" or "catch together".**	*7*
	• **Hence, they look like two pieces of a jigsaw puzzle getting into one another.**	*2*
	• **Another reason why the block remains steady on the table is because there is not enough weight in the tray to start its sliding.**	*5*
	• **There is "grip" when the block remains stationary, but there is "friction" when it "moves" or "rubs" on the table.**	*2*
	• **There is "less friction" or "a little bit" of it when the block starts sliding.**	*5*
	• **There is "very little" or "no friction" when the block is sliding on ice.**	*2*

Table 4.4.3: A synopsis of the groupings of conceptions and alternative conceptions from the analysis of the "block of wood on the table" instance with respective numbers of children's responses (*NoR*).

4.4.d. The card with 'the box on the slope' instance

*Four children (**And, Ia, Is, Ha**) appear to be holding a conception that the main reason for the motionless condition of the box on the slope is the roughness of surfaces which are "uneven" or "jagged" and they "grip" or "catch" with each other.*

(**And**) appears to be considering the existence of friction "under the box" and at the touching points of the slope with the floor and the back of the truck (037). He suggests that if the slope becomes steeper then the box will slide down because "those tiny picks and valleys" (038) won't grip any more and points out that the "roughness of surfaces is always important" (040), or that "friction actually depends on the roughness of surfaces (042).

037	**And**	well .. there is friction there .. under the box .. umm .. and there's some friction there and there .. I mean .. that's where the slope is touching the surface of the road .. and err.. the back of the truck ..	[pointing along the surface of the box that is touching the slope] [pointing at the edges of the slope]
037.5	**Int**	>> umm hmm ..	
038	**And**	.. but say .. if that slope was more steep .. it just wouldn't have any chance to grip .. so it would slide down .. 'cos the box won't be able to grip on those tiny peaks and valleys .. and everything ..	
039	**Int**	I see .. is there anything else you would like to add here .. /	
040	**And**	well .. the roughness of the surfaces is always important .. when you have friction .. say this box is made carbonate .. and it is rough .. but if .. say .. it was made out of glass .. then it would probably slide down .. even here .. 'cos glass is smoother .. isn't it .. /	[pointing at the card]
041	**Int**	yeah .. I see ..	
042	**And**	that's what I mean .. when I say that friction actually depends on the roughness of the surfaces ..	

Similarly, (**Is**) points out that the surfaces are "uneven", they "have little hills and valleys and when they come together" they "catch with each other", much like two pieces of a jigsaw puzzle (044), the analogy that was presented in class during the teaching intervention. She also emphasises that there is "a lot" of friction to keep the box stationary on the slope (044).

043	**Is**	there's a box left on a slope at the back of a truck .. it is not sliding down .. do you think there is any friction here .. / .. umm .. yeah .. there is ..
043.5	**Int**	>> umm hmm ..
044	**Is**	.. because .. the surfaces are uneven .. say the wooden box and the wooden slope .. have little hills and valleys and when they come together .. they catch with each other .. just like two pieces of the jigsaw puzzle .. and if the box does not slide down there's **a lot** of friction keeping it there ..

*Three children (**Pa, Da, Ph**) appear to be viewing gravity as a force that is constantly pulling the box downwards "helping" friction, in a way, to keep the box steady on the surface of the slope.*

(**Pa**) seems to be suggesting the there is friction "on both of the surfaces" of the slope and the box (044), but he also indicates that gravity is pulling the box down as "an extra force all the time" (046). Thus, he regards that the "bits that are hanging out of each surface", "catch into each other", resembling to two pieces of a jigsaw. That creates friction which, together with gravity, "stick the box on the slope" (048).

044	**Pa**	there's a box left on a slope at the back of a truck .. it's not sliding down .. do you think there is any friction here .. / .. *(cough)* .. yeah .. that part of the surfaces there .. under that box .. there's friction on both of the surfaces there ..
045	**Int**	yeah ..
046	**Pa**	so .. it is quite stable where it is.. you see .. also gravity is pulling it down and that's an extra force all the time ..
047	**Int**	well .. could you explain a bit .. what happens between the surface of the box and the surface of the slope .. /
048	**Pa**	well .. yeah .. there's friction there .. 'cos with friction it's just like stuck together .. right there .. those bits that are hanging out of each surface .. catch into each other .. say like the jigsaw .. and that creates friction .. and that .. together with gravity .. sort of stick the box on the slope ..

(**Ph**) appears to be analysing gravity in two components, one vertical pulling downwards and one pulling along the surface of the slope. He suggests that friction is pulling the box downwards, in the same direction of the vertical component of gravity, "trying to keep it where it is", because forces "are about equal" (036). Moreover, he views friction as a phenomenon of surfaces, that are "catching with each other" (037 & 041) because they have "nooks and crannies" (037) or "hills and valleys" (039).

036	**Ph**	there's a box left on a slope at the back of a truck.. it is not sliding down.. do you think there is any friction here .. /.. yes there is .. 'cos again there is gravity pulling it that way .. and a bit that way .. forces are about equal .. 'cos friction is also pulling it that way ... holding it trying to keep it where it is ..	[pointing downwards, along the surface of the slope and downwards again]
036.5	**Int**	>> umm hmm..	
037	**Ph**	.. and just like before .. they are catching on each other .. 'cos there are nooks and crannies on the .. on the wood of that slope .. and nooks and crannies on that box .. so they are catching with each other ..	
038	**Int**	what do you mean when you say .. nooks and crannies .. /	
039	**Ph**	nooks and crannies .. you know .. just like hills and valleys ..	
040	**Int**	all right .. and how do you think that they .. catch with each other .. as you mentioned before .. /	
041	**Ph**	well .. they are catching on each other.. like .. the ones coming down from the box catching on the ones going up from the slope.. yeah.. something like that ..	

*Two children (**Jo, An**) appear to be differentiating between "grip" and "friction" and suggest that when the box is steady on the slope, it is "gripping", whereas "friction" is "caused" when the box starts sliding, "rubbing" with the surface of the slope. Moreover, they both mention that the box remains stationary because "the slope is not steep enough" and gravity keeps pulling it downwards.*

(**Jo**) appears to be considering that the box remains "steady" because it "is gripping" on the slope which is made of wood and "it's not really steep either" (050). If the slope was steeper then the box would slide down, rub on the wooden slope and "that would cause some friction" (052). Hence, when the box is sliding, there is gravity pulling it down and "there is more rubbing" causing "friction" (054), which appears to be different from "grip", in the case of the stationary box on the slope.

050	**Jo**	the box is gripping on that slope .. say .. if the slope is made of wood ... then it is rough .. so the box can grip on it .. and stay steady on it .. it's not really steep either ..
051	**Int**	what would happen if the slope was more steep .. /
052	**Jo**	the box would slide down .. then it would rub on the wooden slope .. and that would cause some friction ..
053	**Int**	do you think that the box is gripping when it is sliding down the slope .. /
054	**Jo**	umm .. there is a bit of gripping .. but there's more rubbing .. 'cos gravity is pulling the box down .. and that rubbing causes friction ... that's .. that's what I think ..

(**An**) points out, right from the beginning that, as he thinks, "there is no friction" in the case of the stationary box on the slope (047) and he suggests that gravity keeps the box there (049 & 051) because the slope is "not steep enough" and the box does not slide. He appears to be considering that if the box starts sliding then it "will cause friction" (051 & 057) because gravity is pulling it down. He seems to recognise some "grip" when the box is stationary on the slope, which looks like the two pieces of the jigsaw (056), but he doesn't seem to ascribe to it an important role for the explanation of the phenomenon. On the contrary, he appears to be considering as more important the force of gravity and a notion of "resistance" from the slope which holds the box in its place without bending (054).

047	**An**	there is a box left on a slope at the back of a truck .. it is not sliding down .. do you think there is any friction there .. / .. no .. I don't think there is any friction here ..
048	**Int**	why do you think that the box is staying there then .. /
049	**An**	gravity .. /

050	**Int**	how do you think that gravity keeps it there .. /	
051	**An**	well .. as it is just a certain slant .. it's not steep enough for the box to slide .. gravity actually pulls it down to keep it in the same place .. but if it is slanting more .. gravity will be able to pull it down .. so .. the box will slide .. and that will cause friction ..	
052	**Int**	any idea what is happening at the touching surface of the box and the slope .. / .. in this situation that the box is not sliding .. /	[pointing at the card]
053	**An**	umm .. it depends .. there will most probably be grip .. but there's mostly gravity helping it stay there ..	
053.5	**Int**	>> umm hmm ..	
054	**An**	.. and there is always the resistance .. from that slope .. 'cos say if it was a very weak resistance the box would be bending it .. say .. if that slope was made of paper then that box would go right through it .. 'cos .. its weight .. gravity would pull it down through it ..	
055	**Int**	yeah .. I see .. you mentioned something about grip at the touching surface of the box and the slope .. could you explain that a bit .. /	
056	**An**	yeah .. there's probably some grip there .. when the box is put on the slope .. just like the pieces of the jigsaw ..	
056.5	**Int**	>> yeah ..	
057	**An**	.. but I still think that friction is caused only if the box is sliding .. 'cos gravity is pulling it down ..	

*Three children (**Is, Ha, Pa**) appear to be suggesting that when the slope is lifted higher, the box will start sliding and friction will be "less", or it will get "weak" because gravity is pulling the box more down and the slope "is getting out of the way".*

(**Is**) appears to be suggesting that if the slope gets steeper the box will slide down and there will be "less friction" in that case, because "the slope gets out of the way" and "gravity is pulling the box more down", weakening, in a way, the force of friction (046).

046	**Is**	well .. if the slope was steeper the box would slide down .. and there would be less friction in that case cause there's more force pulling the box downwards .. and when the slope gets steeper .. it sort of gets out of the way .. .. and gravity is pulling the box more down .. er .. 4.. so friction can't really hold it back ..

Similarly (**Pa**) suggests that the box will slide if the slope is lifted a bit higher because "friction cannot keep it there" and the force of gravity is pulling it "more down" (050) because "the slope is getting out of the way" (052).

049	**Int**	I see .. what will happen if we lift up the slope a bit more .. /	
050	**Pa**	the box will slide 'cos friction cannot keep it there and gravity is pulling it more down ..	
051	**Int**	why do you think that .. gravity would pull it a bit more down then .. /	
052	**Pa**	'cos if you lift the slope a bit more up .. it will get a bit like that .. and it will sort get out of the way .. and the box will have to go down .. 'cos gravity is always pulling it .. and now even more .. 'cos the slope is getting out of the way ..	[representing it with his hand]

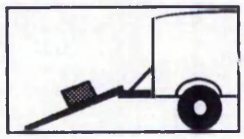
Interview Card	Groupings of conceptions and alternative conceptions	NoR
	• **The roughness of surfaces is the main reason for the motionless condition of the box on the slope because the "uneven" or "jagged" surfaces "grip" or "catch" with each other.**	*5*
	• **Gravity appears to be "helping" friction in keeping the box stationary because it is constantly pulling it downwards, "sticking" it on the table, in a way.**	*3*
	• **There is "grip" when the box is steady and "friction" when the box is sliding" or "rubbing" on the surface of the slope.**	*2*
	• **When the slope is lifted higher, the box will start sliding because friction becomes "less" or "weak", gravity is pulling it more and "the slope is getting out of the way".**	*3*

Table 4.4.4: A synopsis of the groupings of conceptions and alternative conceptions from the analysis of the "box on the slope" instance with respective numbers of children's responses (*NoR*).

4.4.e$_1$. The card with 'the person going down the slide' instance

*Five children (**Da, Jo, Ha, An, Pa**) appear to be thinking of friction between the person and the slide, in terms of "rough", "rubbing surfaces", which seem to be slowing him/her down.*

(**An**) appears to be considering that there is friction "on the actual points that the body is touching the slide" referring to the "shoes" and the "buttocks" of the person (061 & 063). This happens because "there is a force" which holds the person back, slowing him/her down and he "reckons" that it is friction. She suggests that the person "actually rubs" herself on the slide when she is sliding and this causes friction (065).

061 **An** yeah .. A .. coming slowly down the slide .. do you think there is any friction here .. / .. yes .. I do ..
062 **Int** where abouts .. /
063 **An** well .. on the surface of the slide .. and on the actual points that the body is touching the slide .. that is .. at the shoes .. and under his buttocks ..
064 **Int** all right .. how do you think that friction is there ... /
065 **An** umm .. 'cos you can't really go fast down the slide .. there's a force holding you back a bit .. slowing you down .. that's friction I reckon .. er... and you actually rub yourself on the slide while sliding ..

(**Ha**) seems to be suggesting that there is "a bit of friction" at the places that the person is "touching" (052) and "rubbing" (054) the surface of the slide. She indicates that friction "is stopping the person from going fast" (052), or holds him back "a little bit" (054). She discusses it further by pointing out that the person would slide down

faster if the slide was longer, but even then, there would still be "a bit" of friction because the person would "still be rubbing" on its surface (058).

050 **Int** yeah .. coming slowly down the slide .. do you think there is any friction here .. / .. umm ..4.. yeah .. I reckon there's a bit of friction here ..
051 **Int** where abouts .. /
052 **Ha** umm .. at the two places that the person is touching the slide .. that's the shoes .. and at the buttocks .. and that's stopping the person from going fast ..
053 **Int** yeah .. how do you think that friction is stopping the person from going fast down the slide .. /
054 **Ha** because that person .. because he touching the slide .. and he is kind of rubbing on it .. as he goes down .. that creates some friction .. holding him back .. a little bit ..
055 **Int** I see .. anything else you would like to add here .. /
056 **Ha** well .. yeah .. I think he would go down faster if the slide was .. say a bit longer .. that would help him go down faster ..
057 **Int** umm .. that's interesting .. would friction still be there then .. /
058 **Ha** umm .. yeah .. a bit .. 'cos he will still be rubbing on the surface of the slide ..

(**Pa**) appears to be thinking in terms of "rough surfaces" which are "rubbing together" (060) at the touching points of the person and the slide (058) creating "a bit of friction", which holds him/her "backwards" (056).

056 **Pa** yeah ... .A .. coming slowly down the slide .. do you think there is any friction here .. / .. yeah .. there is friction .. on the slide and on the body .. so it's like .. striking together .. that's why the person does not go very fast down .. it goes down slowly you see .. so there's a bit of friction holding him backwards .. sort of thing ..
057 **Int** umm hmm .. where do you think that friction exists here .. /
058 **Pa** well .. as he is sliding down .. there's friction on the slide .. and there .. under his buttocks .. and on his shoes .. those are the touching points .. I reckon ..
059 **Int** I see .. how do you think that friction is created there .. /
060 **Pa** er.. same again we've got rough surfaces .. rubbing together .. as he slides down .. and that creates friction ..

*Two children (**Is, Ph**) seem to be regarding that the "rough" surfaces in contact appear to be "catching on" each other, creating friction.*

(**Is**) appears to be indicating that the person is "sort of catching on" the slide (050) because the "shoes" and the "trousers" are "rather rough", they are touching on the surface of the slide, and as a result "he is catching friction" (052). She suggests that friction slows down the person otherwise he/she "would go down very fast" (053).

050 **Is** yeah .. coming slowly down the slide .. do you think there is any friction here.. / .. umm .. well .. yeah .. because as he is going down the slide .. he is sort of catching on it .. a bit .. 'cos he is sliding ..
051 **Int** well .. what do you mean .. can you explain that a bit please .. /
052 **Is** umm .. as he is sliding down he is catching friction .. on his trousers .. there .. and on his shoes .. that are touching the slide .. which is a rather rough surface .. and .. so he is catching friction ..
052.5 **Int** >> umm hmm .. I see ..
053 **Is** .. and the friction slows him down a bit .. 'cos if he didn't he would go down very fast ..

Similarly, (**Ph**) suggests that the person's "feet", "buttocks" or "trousers" are "catching on the slide while going down" (047). This creates friction which is "trying to hold" the person stationary, but because he/she is sliding, it "slows him down a bit" (049).

047	**Ph**	well .. while he is going down slowly.. his feet are catching .. and his buttocks are catching.. his trousers.. whatever.. that's creating friction.. er.. 'cos he is catching on the slide while going down..	
048	**Int**	I see.. anything else you would like to add here.. /	
049	**Ph**	yeah .. and there's gravity pulling him down that way .. and there's friction holding.. trying to hold him where he is.. but because he is sliding .. it just slows him down a bit..	[pointing towards the ground]

*Two children (**Ia, And**) point out that there will be "a little bit" of friction because the person is sliding or the surface of the slide is rather "smooth".*

(**Ia**) appears to be recognising that there is friction at the touching points of the person and the slide (067 & 069) where they grip (069). She suggests that "all the surfaces touch each other", "go one into the other" and create "a little bit of friction" because, in this case, the person "is sliding" (071).

067	**Ia**	yeah.. going slowly down the slide .. do you think there is any friction here.. / yeah .. there and there ..	[pointing at the points of contact with the slide]
068	**Int**	umm hmm .. could you explain a bit what you mean .. /	
069	**Ia**	yeah .. I mean there is friction at the touching surface of the of the person and the slide .. that's there .. where he is sitting.. and also there.. where the shoes are touching the slide .. and they grip ..	
070	**Int**	what happens when the person is sliding .. /	
071	**Ia**	well .. same again all the surfaces .. touch each other.. go into one another .. and they create .. er.. a little bit of friction .. 'cos he is sliding you see..	

(**And**) appears to be considering that "there is friction" at the touching points of the person and the slide (044 & 046). He suggests that there is "not much friction" though, because slides are "normally very smooth" and there will not be "many tiny bits hanging out of its surface", so "grip" will be difficult (047).

044	**And**	yeah .. coming slowly down with the slide .. do you think there is any friction here .. / er.. there is friction here ..
045	**Int**	where abouts .. /
046	**And**	on the slide .. where he is sitting .. and on his shoes .. that are touching the slide ..
046.5	**Int**	>> umm hmm ..
047	**And**	.. and the slide is probably made out of metal .. and slides are normally very smooth .. so there aren't many tiny bits hanging out of its surface .. err.. I think it will be difficult to grip .. on his trousers and on his shoes .. so there's not much friction here really ..

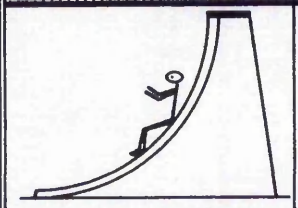
Interview Card	Groupings of conceptions and alternative conceptions	NoR
	• **There is friction at the touching points of the person with the slide because the surfaces are "rough" and they are "rubbing".**	*5*
	• **When the person is sliding, "rough" surfaces are "catching on" each other creating friction.**	*2*
	• **There is a "little bit" or "not much" friction because the person "is sliding" or the slide "is normally very smooth".**	*2*

Table 4..4.5: A synopsis of the groupings of conceptions and alternative conceptions from the analysis of the "person going down the slide" instance with respective numbers of children's responses (*NoR*).

4.4.e$_2$. The card with 'the person holding steady with the hands up on the slide' instance

*Five children (**Pa, Ph, Ia, Da, And**) appear to be suggesting that the person manages to remain steady up on the slide because he/she is "gripping" on its surface, at places of contact like the "shoes", the "buttocks" and the "hands". The latter seem to be gripping "a lot more", in this case, because they are also "forced" at the sides of the slide or the person puts "a lot of power" on them.*

(**Pa**) appears to be indicating that the person's "shoes", "hands", which is "probably the strongest part of the body" (064), and "buttocks" (062) are "gripping" with "a lot of power" and that creates "a lot of friction", keeping the person "steady" on the slide (064).

062 **Pa** umm .. B .. holding steady with the hands at the sides of the slide .. no sliding .. do you think there is any friction here .. / .. yeah .. there is .. 'cos you've got the shoes touching on the slide .. his buttocks .. and also .. with his hands there .. he is gripping .. he creates a lot of friction .. keep himself steady on the slide..

063 **Int** what do you think that is happening with his hands there .. /

064 **Pa** well .. the hands are probably the strongest part of the body .. and that's stopping him from going anywhere .. with his hands been there gripping on the sides .. with a lot of power .. that creates a lot of friction .. enough to hold him steady ..

Similarly, (**Ph**) suggests that the feet, buttocks are "gripping" creating friction (051), but also the person's hands are "gripping" at the sides of the slide and "that's one more friction" which "holds" the person on the slide, "because it has to be stronger than gravity" (052)

051	**Ph**	holding steady with the hands at the side of the slide.. no sliding.. do you think there is any friction here.. /.. yeah there is.. there's gravity.. across.. emm.. there's some friction as in that drawing *(B)* .. with his feet .. and his buttocks.. griping.. and with his hands trying to hold himself up there..	
051.5	**Int**	**>>** umm hmm..	
052	**Ph**	.. so .. there's friction with his hands ..they are griping at the sides of the slide.. stopping him from sliding.. and that's one more friction there.. because it has to be stronger than gravity .. to hold him where he is.. this type of thing..	

(**And**) appears to be using an example to explain the phenomenon by saying that it is like when he is trying to push his hands on the surface of the table and they can't move easily because they grip (053). Hence, he suggests that because the palms "are rather rough surfaces" and they are also forced at the sides of the slide, the "grip" becomes "a lot stronger", holding the person steady on the slide (055).

053	**And**	umm .. well .. it's just like me trying to push my hands .. like that on this table .. they grip and I can't move them easily .. same thing with him there ..	[represents it with his hands on the table]
054	**Int**	how do you think that his hands are gripping at the sides of the slide .. /	
055	**And**	umm .. our palms .. they are rather rough surfaces .. so they can easily grip on other surfaces .. and if we also force them .. as he does here .. then we make that grip .. a lot stronger .. that's what I reckon ..	

*Two children (**Is, Ha**) appear to be considering that the person is "catching friction" at the various points of contact of his/her body with the surface of the slide. Hence, the person is forcing his/her hands by putting a lot of "pressure" or "power" on them in order to "catch friction" or "grip" and remain motionless up on the slide.*

(**Is**) appears to be indicating that the person's hands "are catching a lot of friction" and since the "weight" is pulling the person down, "he has to catch more friction" in order to "stay up" on the slide (057). Thus, the person is "catching friction" because "he is forcing" his hands, "putting a lot of pressure at the sides of the slide", creating "more friction" and, she suggests that, it will be more friction, just like the case when two blocks are slid on the surface of the table instead of one (059).

057	**Is**	oh .. yeah .. I see .. well .. his hands are catching a lot of friction then .. 'cos his weight is pulling him down .. and if he wants to stay up on that slide .. he has to catch more friction on it ..	
058	**Int**	catch more friction on it .. what do you mean .. /	
059	**Is**	well he is catching more friction with his hands there .. 'cos he is forcing them .. putting a lot of pressure at the sides of the slide .. and that creates more friction .. like there would be more friction if you put two blocks of wood on the table .. one on top of the other .. as we did a few days ago .. that sort of thing ..	[pointing at the person's hands]

Similarly, (**Ha**) appears to be suggesting that the person's "shoes", "buttocks" and "hands" are "catching and gripping a lot" in order to hold the person steady (060). Hence, she points out that the person is "actually forcing his hands" by putting "a lot of power on them" in order to "grip really strong at the sides of the slide" and "catch very much friction" (062).

060 **Ha** holding steady with the hands at the sides of the slide .. no sliding .. do you think there is any friction here .. / .. yeah .. there is friction here .. 'cos he is .. his shoes are catching on the slide .. his buttocks are catching .. sort of .. and also his hands are catching and gripping a lot .. holding him steady .. right there ..
061 **Int** how do you think that his hands are gripping .. /
062 **Ha** well .. he is actually forcing his hands to hold him up there .. he is putting a lot of power on them .. so they grip really strong at the sides of the slide .. so he's catching very much friction there .. 'cos he is gripping a lot ..

*Two children (**Jo, An**) appear to be differentiating between "friction" and "grip" by suggesting that in the case of the person staying steady on the slide there is "grip" but not "friction". They appear to be suggesting that there will be "friction" only in the case that the person is going down the slide.*

(**Jo**) suggests that there is "a lot of grip" (065 & 070) because the person is "gripping with his hands at the sides of the slide" (065) by "forcing" them there (068), whereas gravity is pulling the person down. But, she appears to be emphasising that "there is no friction" because the person is not sliding down. Instead "he is holding himself up there" and she claims that "you can't say that grip is friction really" (070).

065 **Jo** .. holding steady with the hands at the sides of the slide .. do you think there is any friction here .. / .. well .. there's a lot of grip .. 'cos he is gripping with his hands at the sides of the slide ..
065.5 **Int** >> yeah ..
066 **Jo** .. but I think there is no friction .. 'cos he is not sliding down .. he is just holding himself up there ..
067 **Int** how does he manage that .. /
068 **Jo** umm .. he is forcing his hands at the sides of the slide .. holding them with all of his strength really .. so gravity can't pull him down .. and so he stays there .. [pointing at B situation]
069 **Int** I see .. but you think there is no friction here .. is that what you mean .. /
070 **Jo** yeah .. no friction 'cos he is not sliding .. it's just a lot of grip .. and ... umm .. you can't say that grip is friction really ..

Likewise, (**An**) points out that since the person "is holding himself" motionless, without "any sliding", "there is no actual cause to make friction" (067) and he explains that "there is only grip" (070) because the person is "grasping the sides of the slide with his hands" (069), but his "shoes" and "buttocks" are also "gripping" in

order to "beat" gravity (070). Hence, he appears to be suggesting that there would be friction only if the person was sliding.

067 **An** .. B .. holding steady with the hands at the sides of the slide .. no sliding .. do you think there is any friction here .. / .. well as he is holding himself up there .. without any sliding there is no actual cause to make friction ..
068 **Int** I see .. what about his hands that are holding steady at the sides of the slide .. /
069 **An** umm .. no friction there .. just the grip .. 'cos he is grasping the sides of the slide with his hands .. umm ...
069.5 **Int** >> yeah ..
070 **An** .. same thing with his shoes and his buttocks touching the surface of the slide .. but since there is no sliding .. there's no friction .. there's only grip .. and gravity .. pulling him down .. but he manages to stay up because .. he is putting a lot of force there with his hands .. umm .. to beat gravity .. I suppose..

*In the question "Where do you think there is more fiction? In **A** or in **B** situation?" all of the children responded that there is more friction in B situation and they attempt to explain it in various ways such as those that follow.*

For example (**Ia**) mentions that in *A* situation "there is not much grip" because the is sliding, but in *B* situation "his hands give him an extra grip" and that creates more friction to keep the person "still" (077).

076 **Int** umm hmm.. I see .. do you think there is more friction in B situation or in A.. /
077 **Ia** umm .. really on A there is not much grip.. it's only his shoes and his buttocks that are touching .. a bit really.. that's not enough so he is sliding.. er.. in B.. his hands give him extra grip.. so that's more friction .. so he can stay still ...

Likewise, (**Is**) appears to be suggesting that the person "has to grip a lot more" in B situation to manage to stay "steady up there" (059).

058 **Int** where do you think that there is more friction .. / .. in A or in B situation .. /
059 **Is** umm .. in B .. 'cos he has to grip a lot more to keep himself steady up there .. [pointing at the slide in B drawing]

(**Da**) suggests that "there are more points of contact" and thus "there are more places for friction" which keeps the person up on the slide in B situation (061).

060 **Int** I see .. in which case do you think there is more friction .. / .. in A or in B .. /
061 **Da** in B .. 'cos there are more points of contact .. and he is staying up there steady .. so there are more places for friction .. to go .. that's it ..

(**Pa**) appears to be rather sure when he says "it's definitely *B* situation" because there is "more grip" with the person's hands (066) and he also points out that "the power from his hands and friction" somehow manage to "beat the force of gravity" and keep the person still up on the slide (068).

065 **Int** umm hmm ... in which situation there is more friction then .. in A or in B .. /
066 **Pa** in B situation .. 'cos he is not sliding .. he is steady .. and you've got more grip there .. with his hands err .. it's definitely B situation ..
067 **Int** all right .. anything else you would like to add here .. /
068 **Pa** yeah .. I think in situation B .. the power from his hands and friction .. beat the force of gravity .. sort of thing .. so he manages to stay steady on the slide .. without sliding down ..

(**Ha**) indicates that since in *B* situation the person "is not moving", there "has to be a lot more friction to beat the force of gravity" which pulls him/her down (064).

063 **Int** where do you think there is more friction .. / .. in A or in B situation ..
064 **Ha** umm .. in B situation .. 'cos he is not moving .. so there has to be a lot of friction to beat the force of gravity .. that is pulling him down .. 'cos he is staying up there .. you see.. yeah .. that's it..

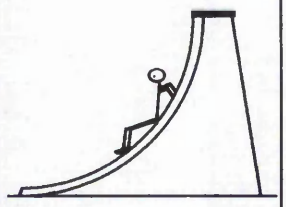
Interview Card	Groupings of conceptions and alternative conceptions	NoR
	• **The person is "gripping" more at the contact areas with the slide and especially with the hands that are "forced" at the sides of the slide or the person is putting a lot of "power on them" in order to stay still.**	*5*
	• **The person is "catching friction" at the contact areas with the slide in order to remain stationary up on it.**	*2*
	• **There is "gripping" when the person is motionless up on the slide, whereas there is "friction" when he/she is sliding.**	*2*
	• **There is *more* friction when the person is stationary up on the slide because there is "extra grip", there are "more points of contact" for friction, or it just "has to be more grip" to have that effect.**	*9*

Table 4.4.6: A synopsis of the groupings of conceptions and alternative conceptions from the analysis of the "person holding steady with the hands up on the slide" instance with respective numbers of children's responses (*NoR*).

4.4.f. The card with 'the slow-down of the bicycle' instance

*Five children (**Pa, Ha, Jo, Is, Ia**) appear to be considering that there are two reasons for the deceleration of the bike, which they probably view in combination to one another. Hence, there is "no more power" or "no more pushing force" to move it along, but at he same time they seem to recognise the existence of friction at the touching points of the tyres and the ground as a cause for the slow-down of the bike.*

(**Pa**) appears to be considering that the bike is slowing down because there "is no more power to push it forward" and because there is "friction on the tyres" (070) which are "rough surfaces" and they have "sort of crannies" that rub on the "rough"

surface of the road (071). He suggests that "it's like the crannies of the tyres are hitting the rough bits of the road" (072) and that creates friction (073).

070	**Pa**	no brakes .. no pedalling .. slowing down .. do you think friction slows down the bike .. / .. yeah .. well the bike is slowing down 'cos there is no more power to push it forward so it'll stop soon .. there is also friction on the tyres that are spinning round .. and they rub on the road ..
071	**Int**	yeah.. what do you mean when you say that the tyres are rubbing on the road../
072	**Pa**	well the tyres are made to be rough .. they have rough surfaces .. they have sort of crannies .. and they rub on the road .. err which is also rough .. it's like the crannies of the tyres are hitting the rough bits of the road ..
072.5	**Int**	>> umm hmm ..
073	**Pa**	.. so that creates friction which slows down the bike ...

Similarly, (**Ha**) indicates that "the tyres are rubbing on the ground" because they have "rough surfaces" and the road is "bumpy" so "they hit the bumps of the road" creating friction (066 & 069). She points out though, that the bike will stop moving because "there is also no more power from the rider to keep it going" (067).

066	**Ha**	no brakes .. no pedalling .. slowing down .. do you think friction is slowing down the bike .. / .. umm .. yeah .. 'cos the tyres are rubbing on the ground when they are going round ..
066.5	**Int**	>> umm hmm ..
067	**Ha**	.. so.. that will slow down the bike and eventually stop it .. 'cos there is also no more power from the rider to keep it going ..
068	**Int**	yeah .. how do you think the tyres are rubbing with the ground .. /
069	**Ha**	umm .. the road is bumpy .. and the tyres have rough surfaces .. and when they roll on the ground .. they just hit the bumps of the road .. they rub on them while going round .. and that creates friction that slows down the bike ..

Also (**Ia**) suggests that the tyres of the bike are "uneven" and they have some sort of "scratches" which are catching on the "ups and downs" of the "rough" surface of the road creating friction (083). But, at the same time, he says he knows that the bike is slowing down because "the rider is not pedalling any more" and consequently "there is no more power" to keep the bike going (085)

083	**Ia**	well .. the tyres of the bike .. are uneven like.. they've got scratches like.. and they catch on the road.. 'cos the road is rough as well ..you see .. it has ups and downs.. and the scratches from the tyres get into them and they kind of .. hold the bike back .. 'cos they create friction ..
084	**Int**	do you think that slows the bike down .. /
085	**Ia**	yeah .. the friction on the tyres .. 'cos the rider is not pedalling any more.. so there's no more power from there.. and.. I know it's slowing down .. so it must be friction from the tyres.. that holds it back and it'll stop soon..

*Two children (**Ph, An**) appear to be putting some emphasis on the roughness of the surfaces of the tyres and the ground, which create "a lot of" friction when they are "rubbing" or "getting into one another".*

Thus, (**Ph**) appears to be rather certain that "friction on the tyres" slows down the bike (058) because the tyres are made of "a rough surface" and as they are rolling they appear to be getting into the road. The road is also "very rough" and "it'll sort of strike" the tyres (062), but things happen "the other way round" as well (060). This, as he suggests, will create "a lot of friction" and will make the tyres hot because they are rubbing (062).

058	**Ph**	no brakes no pedalling slowing down .. do you think friction is slowing down the bike.. / .. yeah .. it's definitely the friction on the tyres that slows it down ..
059	**Int**	what do you mean.. /
060	**Ph**	er.. the tyres have a rough surface.. they are made that way .. so when they are rolling round on the road.. they are sort of getting into it .. and also the other way round..
061	**Int**	>> umm hmm ..
062	**Ph**	'cos the road is also very rough.. and it will get into the tyres a bit.. it'll sort of strike them .. as they're rolling on it .. that creates a lot of friction which slows down the bike.. and also the tyres get a bit hot.. 'cos they rub on the ground..

Similarly (**An**) appears to be "quite sure" that friction on the tyres is the reason for the slow-down of the bike (074) because the tyres are "rubbing on the road" since they have "rough surfaces" with "crannies" and the road has "some sort of grooves". Thus, when the tyres "hit on those grooves" it creates "too much friction" which slows down and eventually stops the bike (077).

074	**An**	no brake .. no pedalling .. slowing down .. do you think friction is slowing down the bike .. / .. umm .. yes .. I think so .. friction on the tyres .. I'm quite sure ..
075	**Int**	what do you mean .. /
076	**An**	well .. the tyres are rubbing on the road .. 'cos the bike is still moving .. but they also have rough surfaces .. some sort of crannies I could say ..
076.5	**Int**	>>..yeah ..
077	**An**	.. and the road is also rough .. it has grooves .. sort of.. and when the tyres are touching it .. rubbing on it .. they actually hit on those grooves .. that creates too much friction .. which slows down the bike .. and it stops it sooner or later..

*Two children (**Da, And**) are pointing out some properties of "rubber" which, as they seem to believe, ascribe special characteristics to the tyres and they attempt to build their reasoning for the slow-down of the bike around that conception.*

Hence, (**Da**) appears to be suggesting that the friction on the tyres is slowing down the bike (065) and this is because the road is "bumpy" and has an "uneven surface". But also the tyres are "rough" and have "kind of crannies" and they "grip on the bumps of the road" (067). He points out though, that the "material of the tyres" which

are made of "rubber" (067), appears to be an important element, since "rubber is rather sticky" and that increases the friction, because the tyres "are gripping a lot more". It wouldn't be the same if they were made out of wood for instance (069).

065 **Da** no brakes .. no pedalling .. slowing down .. do you think friction slows down the bike .. / .. well yeah .. friction on the tyres .. that slows it down ..
066 **Int** can you describe how do you think that happens .. /
067 **Da** well .. the road is bumpy you see .. 'cos it's always an uneven surface .. and the tyres .. they are sort of rough .. and they have kind of crannies .. that grip on the bumps of the road .. and slow down the bike .. and eventually stop it .. er ..4.. it's also the material of the tyres .. 'cos they are made of rubber you see..
068 **Int** why do you say that about rubber .. /
069 **Da** well .. rubber is rather sticky .. I suppose .. that would increase friction wouldn't it .. / .. 'cos it will be gripping a lot more .. than say wood or something like that ..

Likewise, (**And**) indicates that the tyres are made of "rubber" and they "have sort of crannies", which "get into the roughness of the road" and slow down the bike (061). He discusses it further, by mentioning that rubber tyres "help" create more friction because "rubber holds things" (063) and "puts more grip" on the tyres (064). On the contrary though, he suggests that if they were made of wood they would slip on the road (064).

061 **And** well .. there's friction on the tyres .. 'cos they are made of rubber .. and they have sort of crannies on them .. so the get into the roughness of the road .. and that will slow down the bike and it will soon stop moving ..
062 **Int** why did you mention that the tyres are made of rubber ... does that make any difference here .. /
063 **And** yeah .. rubber tyres help friction really .. sort of .. they create more of it .. 'cos rubber holds things .. in a way ..
063.5 **Int** >> umm hmm ..
064 **And** .. 'cos say if .. if .. the tyres were made out of wood .. they would probably slip on the road .. but rubber puts more grip on them ..

Most of the children (**Ph, And, Is, Pa, Ha, Jo, An**) appear to be sensing the existence of friction at various other places of the bike, apart from the tyres. Thus, they suggest that there is friction at the handlebars, where the hands of the person hold tight, at the saddle, where the person sits, at the pedals, where the shoes are rubbing, at the brakes, when they are used and even at the chain of the bike, which they advise that has to be kept oiled.

Hence, (**Ph**) suggests that there is some friction on the saddle of the bike because the person's trousers are rubbing on it and on the pedals where the shoes "are creating some friction" (064).

064 **Ph** umm .. yeah.. there's some friction on the saddle where the rider is sitting .. 'cos his trousers are rubbing on it .. and also there is friction on the pedals .. where his shoes are creating some friction .. umm that's all the friction I can see here..

Likewise, (**An**), keeping in mind his differentiated conception between "friction" and "grip" (cf. analyses of previous cards), indicates that there is "some grip" at the touching points of the shoes and the pedals, but also at the saddle and the person, to avoid possible slippage in both cases (079).

078 **Int** yeah .. I see .. anything else you would like to add here .. /
079 **An** yeah .. there is some grip .. at the shoes and the pedals .. so the shoes don't slip when they are on them .. and also .. at the saddle there.. there must be a bit of grip .. so he doesn't slip off it .. that's what I reckon .. [pointing at the saddle]

(**And**) points out that there is some friction on the pedals and some grip on the handlebars, but also a "bit of friction" on the chain, where oil must be put to "make it turn round a lot easier" (066).

065 **Int** all right .. I see .. is there any more friction anywhere here .. /
066 **And** er .. yeah .. at the pedals his shoes that are touching the pedals .. I mean also at the saddle .. where he sits .. and he is also gripping with his hands on the handlebars.. umm .. there's a bit of friction at the chain as well .. that's why you put oil there .. to make it urn round a lot easier .. that's all I suppose ..

(**Pa**) is indicating that there is friction at the saddle and at the pedals, but also at the brakes when they are used to slow down the bike "faster" (075). He points out that they "catch on the wheel", making a "funny noise sometimes" and they "wear away" because of rubbing (077 & 079), so they need to be changed "from time to time" (077).

074 **Int** I see .. anything else you would like to add here .. /
075 **Pa** yeah .. there is also friction on the saddle ... and on the pedals .. and also at the brakes .. when he is using them to stop .. faster ..
076 **Int** umm hmm .. yeah ..
077 **Pa** er .. you see with the brakes .. they catch on the wheel .. they make a funny noise sometimes .. they wear away 'cos they rub too much .. so you have to change them from time to time ..
078 **Int** do you think friction wears them away .. /
079 **Pa** yeah .. friction .. rubbing .. same thing here ..

*Two children (**Ia, Ha**) appear to be considering the role of the "wind" or "air" as a retarding medium in the slow-down of the bike.*

Thus, (**Ia**) appears to be suggesting that "the air creates a little bit of friction" (086) because as the person and the bike move through the air it is like "pushing" them

backwards, a push that will be stronger if it is "windy" (089). Hence, the air is like "hitting your body" slowing you down and, as he appears to conclude, "it must be friction" (091).

086 **Int** I see .. anything else you would like to add here.. /
087 **Ia** umm .. yeah .. the air.. also creates a little bit of friction ..
088 **Int** what do you mean .. /
089 **Ia** er.. when the person and the bike go .. go through the air.. it's just like.. you can feel it on your face.. err.. air is like pushing you backwards.. say a little bit .. and if it is windy .. that will be a stronger push ..
090 **Int** do you think that this is any sort of friction from the air then .. /
091 **Ia** yeah .. 'cos .. it's like.. air hitting your body .. that slows you down .. so it must be friction .. that's what I reckon ..

Similarly, (**Ha**) appears to be implying that the wind could slow down the bike faster "if it is blowing from the front of the rider" (071), but she seems a bit hesitant to recognise it as friction and she feels more comfortable to say that the wind "is resisting the movement of the bike really" (073).

070 **Int** all right .. anything else you would like to add here .. /
071 **Ha** yeah .. the wind .. if it is blowing from the front of the rider .. that would slow him down .. faster..
072 **Int** is there any more friction here then .. /
073 **Ha** umm .. I don't know ..it's just like .. the wind is like hitting him .. dragging him back a little bit .. it is resisting the movement of the bike really .. you might call that friction ..

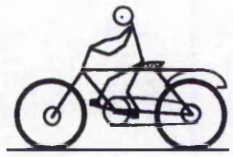
Interview Card	*Groupings of conceptions and alternative conceptions*	*NoR*
	• **The bike is slowing down because there is friction at the touching points of the tyres and the ground, but also there is "no more power" or "no more pushing force" to keep it going.**	*5*
	• **The roughness of the tyres creates "a lot of friction" with the ground because they are "rubbing" or "getting into one another".**	*2*
	• **Tyres have "crannies" and are made of rubber which is "kind of sticky" or "holds things" and that creates friction.**	*2*
	• **There is also friction at the handlebars, the saddle, the pedals or even the chain.**	*7*
	• **The wind could be also slowing down the bike or "resisting" its movement.**	*2*

Table 4.4.7.: A synopsis of the groupings of conceptions and alternative conceptions from the analysis of the "slow-down of the bicycle" instance with respective numbers of children's responses (*NoR*).

Discussion

All of the children in this study appear to have developed and elaborated their conceptions on frictional phenomena within a "surface roughness" theory of friction

(cf. § 2.2), which has strongly been promoted and investigated during the teaching intervention (cf. § 4.2). Thus, friction is "caused" or "created" because surfaces in contact are "uneven", "rough", "jagged" or "ruffled" and they are "like stuck together" or they "get into one another", just like two pieces of a jigsaw puzzle, the analogy that was presented and discussed during the teaching intervention (cf. § 4.2.5). The asperities of the surfaces, or in children's words the "hills and valleys", "tiny picks and valleys", "little tops and valleys", "ups and downs", "tiny bits hanging out of the surfaces", "bumps", "crannies" or "the nooks and crannies", interlock with each other creating friction. Most of the surfaces that children get in touch with in their everyday life are rough and "surface roughness theory" of friction appears to be an intelligible, plausible and fruitful approximation for children, of this age, to explain various frictional phenomena. At least they manage to do so quite successfully in the depicted instances of the interview cards.

Many times children relate friction with "gripping" and "rubbing", and they appear to be using all three terms in the same context for phenomena that happen in the interface of two objects in contact. Hence, they mention that "friction is when two things "rub" or "grip" together. According to children's responses, this can happen when the surfaces are in relative motion to each other on even when they are stationary. This is a finding that does not agree with the findings of Stead & Osborne (1981), who claim that children hold the view that "friction only occurs between moving surfaces" (p. 53). Their interviews though, covered a wider range of learners and were conducted independently from any sort of teaching intervention.

Nevertheless, there are two cases of children (**Jo, An**), who, throughout their interviews, appear to be holding a differentiated conception between "grip" and "friction". They seem to consider that "grip" is when two things are in contact (e.g. book on the tilted table) and remain motionless, whereas "friction" is created only when two objects are in relative motion with each other (e.g. the book sliding down a more tilted table). They are rather hesitant in recognising "grip" as "friction" and they

feel more comfortable in holding separated conceptions. This could be interpreted as a "premature conception" or a "preconception" relative to the distinction between static and sliding friction, since similarities in the ascribed meaning of terms could be drawn between "grip" and "friction" respectively. Alternatively, it could be also claimed that, for these children, "friction" is strongly associated with movement, which is similar to one of the findings of Stead & Osborne (1981, p. 53).

Some children appear to be thinking of "gravity" as an assisting force to friction, because it pulls things towards the ground and somehow "sticks surfaces together", when they are in contact, and this in turn "helps" the interlocking of surfaces, which creates friction. Hence, they are probably viewing gravity as a presupposition for the contact of surfaces and the creation of friction.

It seems that most of the children generally accept that when things are sliding on a surface (e.g. a block of wood on the table, a person going down the slide) there is still some friction, but it appears to be considered "less" than the friction of a stationary body (e.g. a motionless block of wood on the table pulled by some weights). Furthermore, it is suggested that the friction along the interface of two sliding surfaces becomes "weak", or it is reduced to "a little bit". Nevertheless, they appear to believe that "some" is still there because the surfaces are "still rough" and they have to go over the protuberances of each other. If it is considered that the maximum static friction is less than the sliding friction (cf. § 2.3), say for the block of wood on the table, then this conception appears to have a scientific basis, although it would be rather naive to claim that children thought of it in this way.

Some children appear to be viewing the "air" or the "wind" as a retarding medium. Thus, if the wind is blowing against objects, or when they are moving through it, it slows them down, but this is not really considered as "friction". Some children also mention that there will be "very little" or even "no friction" if objects are slid on ice.

4.5.0. Highlighting some aspects of children's conceptual change: Two cases (Jo, Da)

In this section there is an attempt to present and discuss two cases of children on the basis of an overview and comparison between some of the conceptions they expressed in the pre-intervention interviews (**Pre-I.I.**) and those expressed in the post-intervention interviews (**Post-I.I.**). It is anticipated that this will highlight some aspects of their conceptual change, in reference to friction and/or frictional phenomena. Some information is also drawn from concept maps, which children made after the teaching intervention which can be related to the interview data in order to view children's conceptions from a different perspective. Some propositional links between certain words-concepts, which are involved in the concept maps, are reconstructed and commented on. Both of these cases of children are considered to be indicative and they have been chosen because they represent some very interesting aspects of children's conceptual change.

4.5.1. The case of (Jo)

Throughout the **pre-intervention interview**, (**Jo**) appears to be using the word "grip" in terms of "something" that "just" happens in certain instances, in a rather commonsensical way. It seems that "grip" has to do with the surfaces, or it appears to be a property of some surfaces and/or objects. She does not consider "grip" to be a force, but she mentions that it "holds things" preventing them from "slipping", or even slows things down. Thus, she appears to be holding a notion of "grip" which could be characterised as an intuitive preconception of static friction, although this does not necessarily mean that she thinks of it in this way. She does not point out any further description about the nature or characteristics of the "gripping" surfaces, although she discusses "grip" in reference to a "rough" cover of the "book on the tilted table" instance.

Hence, in the '*man pushing the car*' instance she mentions that "his shoes are gripping on the ground", so the person can push and not "just slip and fall down" (011.5).

011.5 **Jo** **>>** .. also the man's legs are pushing away .. his shoes are gripping on the ground .. so .. he can push really .. and not just slip and fall down .. *(laugh)* the shoes push on the ground and hold him there..

She also suggests that there is "a bit of grip" on the tyres, and that could probably make it difficult for the man to push the car, since she mentions that "there is always grip on the tyres" (013). But, she does not appear to consider this "grip" as a force, and she suggests that the shoes and the tyres are "just gripping on the ground" (015).

013 **Jo** umm ..4.. there must be a bit of grip there as well .. maybe that grip .. that grip makes it difficult for him to move it .. you know.. there's always grip on the tyres .. [pointing at the tyres]
014 **Int** is that .. grip .. a force then .. /
015 **Jo** umm .. no you can't really call that a force .. the tyres .. his shoes also .. are just gripping on the ground ..

In the '*book on the tilted table*' instance she points out that there is "grip again", which, together with the fact that the table "is not steep enough", keeps the book stationary on the tabletop (033). Because the cover of the book "is rather rough", it "could grip" and "hold itself there" (035). She appears to relate it metaphorically with "a brake" and that is probably a characteristic representation of her intuitive preconception of "gripping".

032 **Int** yeah.. but why does the book stay there .. /.. and does not slide down ..
033 **Jo** er .. the table is not steep enough .. or it could be .. a bit.. it could be the grip there again .. [pointing along the surface of the book that is touching the table]
034 **Int** the grip there you say .. can you explain that a bit .. /
035 **Jo** yeah .. the book .. the cover .. is rather rough and it could.. it could grip on the table.. and just hold itself there.. it's like a brake .. you know..

In the '*skateboard*' instance she also considers "grip" on the wheels "while they roll" (049), but again she does not view it as a force (051). She points out that "grip" makes it "difficult" for the skateboard to move, although she also mentions there "is not really any power to keep it going" (053).

049 **Jo** well same as the car .. they *(the wheels)* grip a bit .. while they roll here .. you know that sort of thing ..
050 **Int** is that .. gripping .. a force then .. /
051 **Jo** no .. I don't think it's a force .. /
052 **Int** yeah .. do you think that .. this gripping.. slows down the skateboard and eventually stops it .. /
053 **Jo** umm ..4.. it makes it a bit more difficult to move .. I am not really sure .. I think it slows down 'cos the person .. there's not really any power to keep it going.. no more pushing force from there ..

She appears to be thinking in a similar way for the *'slow-down of the bicycle'* instance when she points out that the bicycle slows down because there is "no more power to keep it going", but also because there is "a bit of help from the grip on the tyres as well" (080), which is "not really a force" (078). Hence, she appears to be recognising a helping role of "grip" in the slow down of moving objects.

078 **Jo** no .. it's just that bit of gripping on the wheels touching the ground.. not really a force .. their weight is pressing down the wheels on the ground ..
079 **Int** I see.. why do you think that the bike slows down and eventually stops .. /
080 **Jo** well .. there's no more power to keep it going.. no pedalling or anything .. a bit of help from the grip on the tyres as well .. that's it ..

(**Jo**)'s preconception of "grip", as it appears to be in the **Pre-I.I.**, or at least as it is interpreted by the researcher, could be represented in a schematic way as follows:

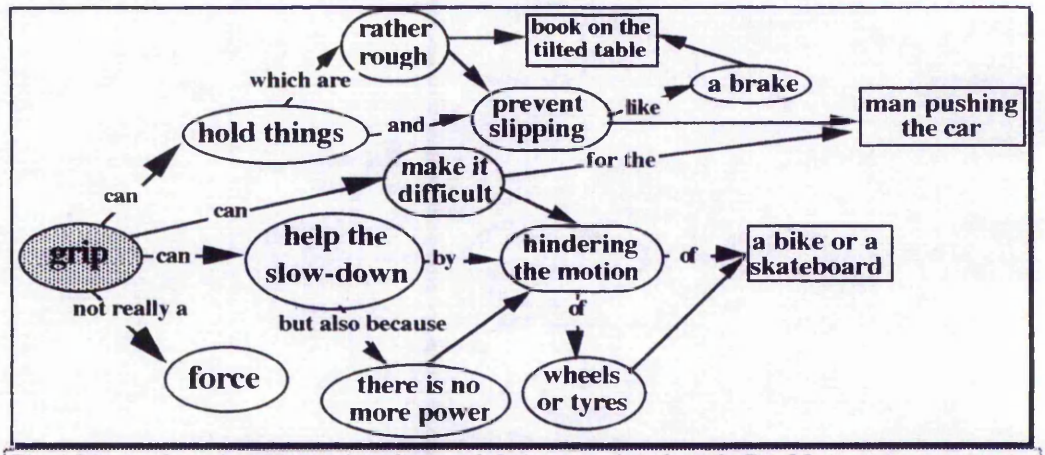


Fig. 4.5.1: A schematic representation of some of (**Jo**)'s conceptions from the **Pre-I.I.**

Throughout the **post-intervention interview**, (**Jo**) appears to have developed a differentiated conception between "grip" and "friction". Hence, she regards that "friction" is when "two things rub together" or when they are in relative motion to each other, whereas "grip" is when two things catch on each other and they remain stationary. She describes "grip" as an effect of rough surfaces with "little hills and valleys" that get into one another, much like two pieces of a jigsaw puzzle, and friction as two "rough" surfaces that "rub" together and move or slide over one another.

In the *'person walking along the road'* instance she indicates that "friction is when two things rub together" (008 & 013). She suggests that when a person walks on the

road, the shoes do not "really rub on the floor", instead they are "just touching" and that "could cause a little bit of friction" (008 & 011). She points out though, that if the person is "sliding" his/her shoes on the ground then they are "rubbing" more, creating more friction (009).

008 **Jo** well .. to start with .. friction is when two things rub together .. but his shoes do not really rub on the floor .. when he walks .. umm .. they're just touching really .. that could cause a little bit of friction ..
008.5 **Int** **>>** umm hmm ..
009 **Jo** .. er .. there could be more friction .. if he is sliding his shoes along the road .. 'cos then he is actually rubbing on the road .. yeah .. that would create friction.
010 **Int** yeah .. but do you think there is any friction .. when we just walk around the room for instance .. /
011 **Jo** umm .. yeah .. but only when you slide your feet on the floor .. when you're just walking .. your shoes are touching the ground .. and the ground is supporting them .. there's not really much friction there .. that's what I think ..
012 **Int** yeah .. but you think there is friction only when you slide your feet on the floor .. /
013 **Jo** yeah .. that causes friction .. 'cos friction is when two things rub together ..

In '*the book on the tilted table*' instance, she points out with emphasis that the book is "gripping" and that's how it remains stationary on the table (019), but she also appears to suggest that "grip is a kind of friction (025). She seems to be rather certain that there is friction in the case that the book starts sliding on the tabletop, because "it would be gripping then" (025).

019 **Jo** umm .. the book is **gripping** on the table .. that's the only way that it can stay there .. as far as I can think of ..

025 **Jo** umm .. I think grip is a kind of friction .. but I would say there would be definitely friction when the book slides down the table .. 'cos that would be rubbing then .. wouldn't it .. /

Furthermore, she describes her conception of gripping as a phenomenon "of the roughness of surfaces" that "get into one another" and "grip", like "two pieces of a jigsaw puzzle" (021 & 023).

020 **Int** the book is gripping .. you say .. can you explain that a bit .. /
021 **Jo** yeah .. it has to do with the roughness of the surfaces .. 'cos both of the surfaces are rough here .. I mean the book and the table ..
022 **Int** what happens then .. /
023 **Jo** they get into one another .. it's just like the two pieces of the jigsaw .. so they grip .. in a way .. and that's why the book stays there ..

Similarly, in the '*block of wood on the table*' instance she suggests that the block is "gripping" on the table (031) and this is due to the "roughness of surfaces" and the "little hills and valleys coming out of each of these surfaces" (034) (cf. § 4.4.c).

When the block is sliding she points out that there will be "some friction but not grip" (040). She suggests that there is "grip" when the block is "stationary", but there is friction when "it is rubbing on the table" (044).

038 **Jo** yeah .. there is 'cos the block of wood is rubbing on the table .. 'cos it's sliding .. and that creates friction .. er.. it doesn't grip much though ..
039 **Int** what do you mean .. /
040 **Jo** well .. there is some friction but not much grip ..
041 **Int** are these two different .. /
042 **Jo** yeah .. I think so ..
043 **Int** in what way .. /
044 **Jo** there's grip when the block of wood is .. stationary .. but then when it is sliding there is friction .. 'cos then it is rubbing on the table .. that's how it happens ..

Likewise, in the '*box on the slope*' instance she suggests that there is "grip" when the box is stationary because the wooden surface of the slope is "rough" (050). She also points out that there is "a bit of gripping" when the box is sliding down the slope, but there is more "rubbing" in that case, which "causes friction" (052 & 054).

050 **Jo** the box is gripping on that slope .. say .. if the slope is made of wood ... then it is rough .. so the box can grip on it .. and stay steady on it .. it's not really steep either ..
051 **Int** what would happen if the slope was more steep .. /
052 **Jo** the box would slide down .. then it would rub on the wooden slope .. and that would cause some friction ..
053 **Int** do you think that the box is gripping when it is sliding down the slope .. /
054 **Jo** umm .. there is a bit of gripping .. but there's more rubbing .. 'cos gravity is pulling the box down .. and that rubbing causes friction ... that's .. that's what I think ..

In the '*person going down the slide*' instance she points out that there is "friction" at various "touching points", such as the shoes and the trousers, because the person is "rubbing on the surface of the slide" (058).

058 **Jo** yeah .. coming slowly down the slide .. is there any friction here .. / .. yes there is friction here .. 'cos he is rubbing on the surface of the slide ..
059 **Int** where do you think that friction exists .. /
060 **Jo** umm .. at the touching points .. I mean .. at his shoes.. and where he is sitting .. at his trousers.. let's say .. er ..4.. he is rubbing himself there .. so that's causing friction ..

In the '*person holding steady with the hands up on the slide*' instance she indicates that there is "a lot of "grip", because the person "is gripping with his hands at the sides of the slide" and remains unmoved (065). She points out though, that there is "no friction" because the person "is not sliding down" (066).

065 **Jo** .. holding steady with the hands at the sides of the slide .. do you think there is any friction here .. / .. well .. there's a lot of grip .. 'cos he is gripping with his hands at the sides of the slide ..
065.5 **Int** >> yeah ..
066 **Jo** .. but I think there is no friction .. 'cos he is not sliding down .. he is just holding himself up there ..

Thus, she suggests that there is "just a lot of grip", but she doesn't appear to recognise "grip" as a kind of friction, or as she puts it "you can't say that grip is friction really" (070).

069 **Int** I see .. but you think there is no friction here .. is that what you mean .. /
070 **Jo** yeah .. no friction 'cos he is not sliding .. it's just a lot of grip .. and ... umm .. you can't say that grip is friction really ..

In *'the slow-down of the bicycle'* instance she suggests that there is friction on the tyres, but additionally, as she has also mentioned in the **Pre-I.I.**, there is "nobody pedalling any more" (074). She describes the phenomenon referring to the tyres of the bike, which are made of "rough rubber", like some sports shoes, and they get into the "bumps" of the ground "as they are going round" (076 & 077).

074 **Jo** no brakes .. no pedalling .. slowing down .. do you think friction is slowing down the bike .. / .. yeah .. friction on the tyres .. that's slowing the bike .. and the fact that nobody is pedalling any more ..
075 **Int** what do you mean when you say friction on the tyres .. / .. can you explain that a bit please .. /
076 **Jo** umm .. well .. the tyres of the bike are made of rough rubber .. it's just like some sports shoes .. and the ground is always rough .. and bumpy ..
076.5 **Int** >> umm hmm ..
077 **Jo** .. so .. the tyres .. as they are going round .. they get into these bumps of the road .. and that slows them down .. and the bike is going to stop soon ..

On the whole, (**Jo**) seems to have retained her preconception of "grip" in the **Post-I.I.**, but she appears to have extended it by adding more accurate descriptions of the phenomenon of "gripping surfaces". Her explanatory descriptions appear to be based on the "roughness" of surfaces and their interlocking, with the aid of the analogy of the jigsaw puzzle. A new conception of "friction" appears to have formed, which effects the slow-down of "rubbing" or "moving" surfaces. Although there is a rather explicit differentiation between "grip" and "friction", the first referring to stationary situations and the latter referring to situations where motion is involved, she seems to be a bit indecisive whether to consider "grip" as "a kind of friction" (cf. **Post-I.I.**, 025), or not (cf. **Post-I.I.**, 070).

(**Jo**)'s conceptions of "grip" and "friction", as they appear to be in the **Post-I.I.**, or at least as they are interpreted by the researcher, could be represented in a schematic way as follows:

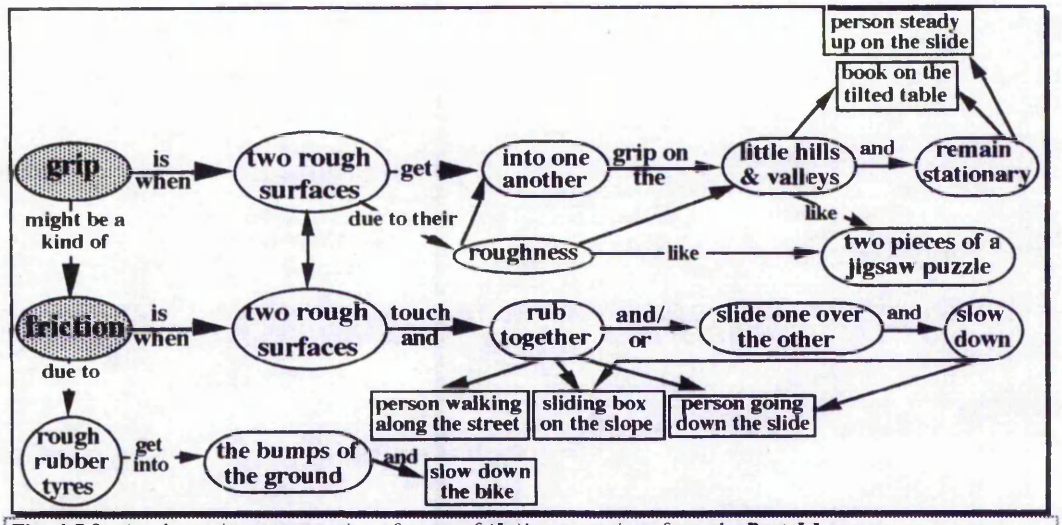


Fig. 4.5.2: A schematic representation of some of (**Jo**)'s conceptions from the **Post-I.I.**

In her concept map, (**Jo**) appears to be considering that "rubbing can cause friction" which is when "tops and valleys interlock" with each other (see fig. 4.5.3). This can have an effect in the motionless condition of a body or "it can slow it down". This, in its turn, happens because "the surfaces are rough". On the other hand, if the surfaces are smooth they can "make things slide". Hence, the surface roughness approximation of friction appears to be explicitly expressed. The propositional link "can be" between "force" and "friction" might be interpreted in two ways at least. Either "friction can be a force" or "a force can be friction". There appears to be a link between these two concepts but it is not clear what the intended meaning of this link is. Although the children were told to feel free to add any other words-concepts that they thought should be included, (**Jo**) does not refer to the word "grip", or any other word related to her conception of "grip". It seems to be a "string" concept map (Novak & Gowin, 1984), with a beginning ("rubbing") and an end (a full stop), without any cross links between words.

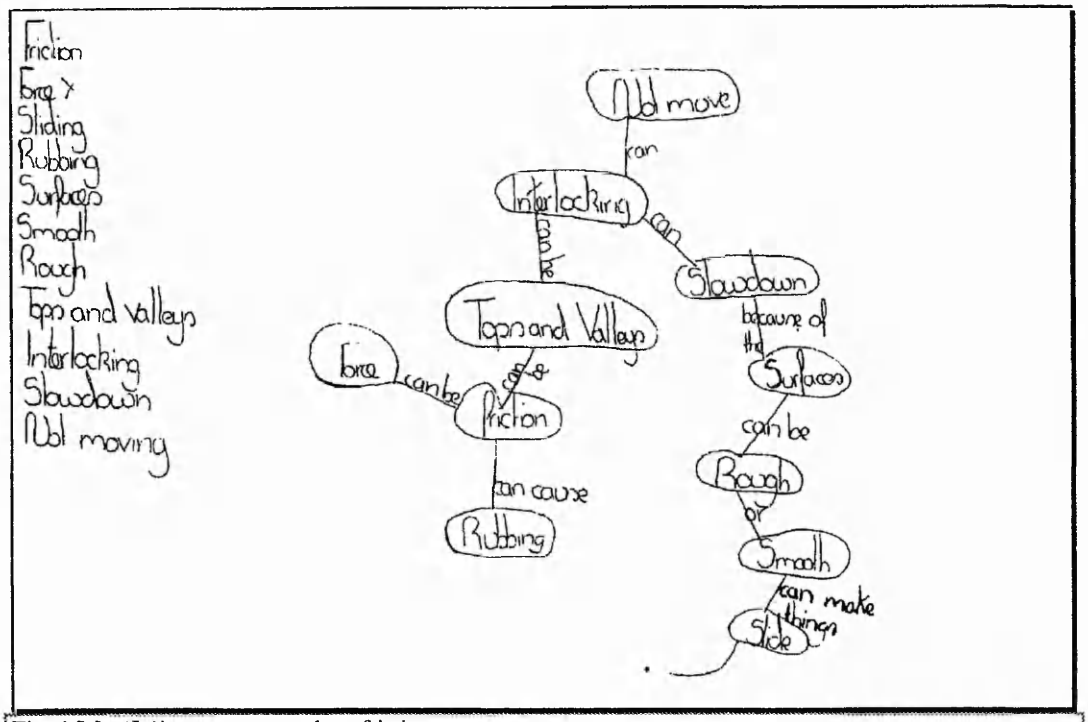


Fig. 4.5.3: (Jo)'s concept map about friction.

4.5.2. The case of (Da)

Throughout the **Pre-I.I.**, (**Da**) appears to be holding a conception that "gravity" is responsible for holding things together or for slowing things down because it pulls everything downwards. He also appears to be holding a conception that various frictional effects, between two surfaces in contact, depend on the "substances" of the bodies that are touching each other. Thus, "rubber" can hold things, whereas "plastic" may let them "roll down".

In the '*slow-down of the bicycle*' instance, when he is asked whether he thinks there are any forces at the touching points of the wheels of the bike and the ground, he appears to be sensing that "there must be forces", but he is not sure if "that's stopping the bike" (016). Thus, he prefers to think in terms of a more familiar conception, that of "gravity" (010), or the "weight" of the person, which "is actually pulling" the bike down, probably implying that it effects its motion (010 & 016). He also appears to

consider the wind as an aid to the rider if it is blowing from the right and as a hindrance if it is blowing from the left, in which case, the bike will slow down "faster" (018).

010	**Da**	well .. it's like .. the gravity is like .. pulls it down .. it's trying to stop it and it's like the force of the weight of the man .. is pushing the bike along ...	
013	**Int**	yeah ...do you feel there are any forces at the touching points of the ground .. /	[pointing at the tyres]
014	**Da**	yeah ..4..	
015	**Int**	what do you mean.. /	
016	**Da**	well .. there must be forces but.. I don't know if that's stopping the bike .. it's just the weight actually pulling it down..	
017	**Int**	any other forces here .. /	
018	**Da**	umm .. the wind .. if it.. if it is blowing behind of him it'll speed him up a little bit .. and if it's blowing this way .. it'll slow down faster 'cos it's pushing him back ...	[pointing at the opposite direction, behind the rider]

In the '*skateboard*' instance he appears to be holding the same kind of conception that "gravity is like pulling it down" and that is stopping it from moving (038 & 039).

038	**Da**	er .. he is not pushing .. umm .. well it's basically same as the bike really 'cos..
038.5	**Int**	**>>** yeah..
039	**Da**	.. er.. gravity is like pulling it down so .. which is stopping it ..

In the '*book on the tilted table*' instance he appears to be considering that gravity would pull the book "along the table and down" but he observes that it does not happen (071). Thus, he considers the possibility of the existence of "grips" on the surface of book, since books "can have ripply covers" and that might hold the book on the table (073 & 075). Then, he suggests that "it depends on the substances" and he points out that "rubber can hold things", whereas "plastic" would let them "roll off a lot easier" (077 & 079).

072	**Int**	do you think there are any forces there ... where the surface of the cover of the book is touching the surface of the table .. /	[pointing at the respective spot at the picture]
073	**Da**	well. .. yeah.. it's touching .. ain't it... it's like ... are there any grips or anything on the book.. /	
074	**Int**	what do you mean .. /	
075	**Da**	well you know.. books can have like.. ripply covers.. can't they .. /	
076	**Int**	yeah .. do you think that could hold the book on the table.. '	
077	**Da**	er.. it might do.. it depends on the substances.. 'cos I know .. like rubber can hold things.. but if it was plastic or like.. like.. it would roll down..	
078	**Int**	do you think the surface of the table has anything got to do with it.. /	
079	**Da**	yeah.. because like .. as I say.. it's different substances.. this is like.. making roll off a lot easier.. or.. just hold it back there..	

In the '*man pushing the car*' instance he suggests that the car remains motionless because the wheels "are being held down onto the ground" (087) due to "gravity" (089), which is "like a big Hoover that sucks everything down onto the ground" (091).

087 **Da** well .. the wheels are like .. being held down onto the ground ..
088 **Int** how do you think that happens .. /
089 **Da** er ..4.. with gravity..
090 **Int** in what way do you think gravity holds the wheels down onto the ground .. /
091 **Da** in what way .. /.. 'cos it's like a big Hoover that sucks everything down onto the ground..

When he is asked whether there are any forces at the touching points of the wheels and the ground he moves back to his conception about "the different substances" and the "rubber wheels" which are "like jammed" (093) and the ground is "rough" and that holds the wheels "in place", because "they would get more into it" or they would "grip more" (095 & 097). He doesn't explain how he understands this "grip" though.

093 **Da** well as I said before.. it's like the .. the different substances.. 'cos it's rubber wheels.. and it's like sort of .. well.. it's like jammed ..
094 **Int** umm hmm ..
095 **Da** and if it is like a rough ground .. it holds the wheels in place ..
096 **Int** what do you mean .. /
097 **Da** they would get more into it .. they would grip more ...

(**Da**)'s conceptions about "gravity" and "substances", with some ascribed frictional characteristics, as they appear be in the **Pre-I.I.**, or at least as they are interpreted by the researcher, could be represented in a schematic way as follows:

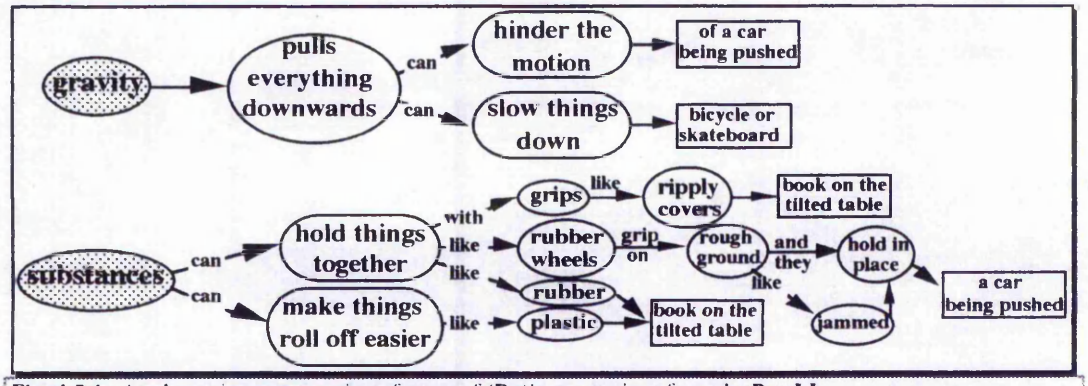


Fig. 4.5.4: A schematic representation of some of (**Da**)'s conceptions from the **Pre-I.I.**

Hence, in the **Pre-I.I.**, (**Da**) appears to be ascribing "frictional characteristics" to "gravity", such as hindering the motion of bodies or slowing things down. He also appears to be holding a parallel conception of "substance dependent" frictional effects. Thus she suggests that different "substances" may "hold things together", or "make things roll off easier". These conceptions could be characterised as intuitive preconceptions of friction and/or frictional phenomena, although they are not named

as such. They constitute intuitive or spontaneous ways of constructing explanations of certain phenomena, even when proper nomenclature is not at the moment available to the learner. Such preconceptions, when tested throughout a teaching and learning process, may help the learner in constructing more advanced explanations, or may equally hinder this process of change by acting as "epistemological obstacles" (Bachelard, 1938; Souque, 1988; cf. § 1.1.1.).

In the **Post-I.I.**, (**Da**) has maintained his conception about the role of gravity in pulling things downwards, "sticking" the surfaces together in a way, "helping" the force of friction. His conception of "friction" appears to depend on the nature of the "surfaces" in contact. Thus, he has somehow changed the term "substances" that he used in the **Pre-I.I.** to the term "surfaces" to refer to special characteristics or properties that they may have. He appears to feel quite comfortable to develop explanations about frictional phenomena within the "surface roughness" approximation of friction, but he also involves the force of gravity in these explanations. He also appears to relate "rubbing" to friction.

Hence, in the '*person walking along the street*' instance he suggests that there would be "more friction" if the person "is dragging" his/her "feet on the ground" because they would "rub more" (008).

008 **Da** .. it would be more friction if you're dragging your feet on the ground .. 'cos they rub more you see ..

In the '*book on the tilted table*' instance he points out rather explicitly that friction "depends on the surfaces" (016). He suggests that the book and the table are "rough" and they "are kind of sticking together" due to their roughness. This wouldn't happen if the table was "smooth" and the book was "plastic", because the book wouldn't grip as much and it would slide down (018). Nevertheless, he also mentions that "first there is gravity holding the book onto the table", "and then" the book grips onto the table surface due to the "little things there" that create friction (020). Thus, he has kept his conception of the role of gravity, but he now also considers the role of

friction, in the motionless condition of the book, which depends on the roughness of surfaces.

016 **Da** we lift the table up a little bit from one of the sides .. the book does not side down .. do you think friction is keeping it there .. / yeah .. it depends on the surfaces ..
017 **Int** yeah .. what do you mean .. /
018 **Da** say if the table surface is rough .. and the cover of the book is also rough .. then .. they're kind of sticking together .. the roughness does that .. but say .. if it was smooth and .. say the book was made of plastic .. then it wouldn't grip as much .. so it would slide down ..
019 **Int** I see .. how do you think that .. the roughness of the book keeps it there .. /
020 **Da** well .. it's hard to explain that .. first there's gravity holding it onto the table .. and then .. if the table is a bit rough .. it will have all these little things there .. and the book would grip on it .. that would create some friction that would help the book stay still ..

Moreover, he appears to be holding the view that the higher the table is lifted, the less friction there is in the interface of the book and the table because gravity is pulling it more "and so it slides" (024). He claims that gravity is pulling the book more towards the ground when it is lifted higher because "it wants to go down immediately", attributing rather anthropomorphic characteristics to the book (026).

024 **Da** well .. the higher the table is .. the less friction is there .. 'cos then gravity is pulling it *(the book)* more down .. and so it slides ..
025 **Int** why do you think that gravity is pulling the book more down .. if we lift the table a bit higher .. /
026 **Da** 'cos it's getting higher off the ground .. so it *(the book)* wants to go down immediately.. I suppose ..

Similarly, in the '*box on the slope*' instance he suggests that there is friction keeping it stationary up on the slope, but there is "also gravity" (042). He describes the phenomenon with a metaphorical representation of "little tops and valleys" that "interlock" with each other. But, there is also the force of gravity that "kind of sticks" the box on the slope and, in that way, "it helps it grip more" (044 & 046). Hence, he contends that "friction and gravity are just keeping the box there" (048).

042 **Da** there's a box left on a slope at the back of a truck .. it is not sliding down .. do you think there is any friction here .. / ..yeah .. this is very similar to the table and the book .. kind of thing .. so there's some friction here.. but also gravity ..
043 **Int** what do you mean .. / .. could you describe that a bit .. please .. /
044 **Da** well .. all the points of contact those little tops and valleys .. inter.. er .. interlock with the slope .. that means they get into one another .. kind of thing .. and that holds the box there .. and also because of gravity ..
045 **Int** what happens with gravity then .. /
046 **Da** er .. it pulls that box down .. but it kind of sticks it on the slope .. 'cos that's in the way .. you see .. so it helps it grip more ..
047 **Int** yeah .. I see .. anything else you would like to add here .. /
048 **Da** no .. that's all .. friction and gravity are just keeping the box there ..

In the *'person going down the slide'* instance he suggests that as the person is sliding, "he is rubbing his jeans and his shoes on the slide" (050). This "rubbing" resembles to the rubbing or two hands which "grip", or "sort of catch on each other", and that's why some "dirt" appears after rubbing them for a while (052). Hence, the person's "buttocks" are rubbing on the surface of the slide and if it was longer "he would feel like burning" (053), just like the hands get warm after rubbing them (055).

050 **Da** yeah .. A .. coming slowly down the slide .. do you think there is any friction here .. / .. yeah .. there is friction here .. 'cos as he is sliding down .. he is rubbing his jeans and his shoes on the slide .. that creates friction and slows him down a little bit ..
051 **Int** how do you think that rubbing creates friction here .. /
052 **Da** well you know .. rubbing .. just like when you rub your hands .. they grip .. 'cos they sort of catch on each other .. I suppose .. that's why you get a bit of dirt in your hands after that ..
052.5 **Int** >> umm hmm .. I see ..
053 **Da** .. and what happens here is that his buttocks are rubbing on the surface of the slide .. and say if that *(the slide)* was a longer one .. he would feel like burning soon .. 'cos he will get hot from all that rubbing *(laugh)*..
054 **Int** all right *(laugh)* .. why do you think that he would get hot then .. /
055 **Da** well his buttocks would get hot .. just like your hands when you rub them .. I don't know really .. it just happens ..

He also points out that there is more grip in *B* situation than in *A*, because there are "more points of contact" and thus, "more places for friction" (061). Hence, it could be claimed that this is another aspect of his conception of friction being surface dependent.

061 **Da** in B .. 'cos there are more points of contact .. and he is staying up there steady .. so there are more places for friction .. to go .. that's it ..

In the *'slow-down of the bicycle'* instance he suggests that the "uneven surfaces" that have "kind of crannies" grip on the "bumps" of the road, create friction and slow down the bike (067). Thus, he remains within the surface roughness approximation of friction, but he also points out a characteristic property of "rubber", the substance that tyres are made of, which is "kind of sticky " and may "increase friction" (067 & 069). Hence, in this case, he appears to be thinking in terms of the "material" that the tyres are made of, which can be claimed that is a more clarified conception from the notion of "substances" that he used in the **Pre-I.I.**

067 **Da** well .. the road is bumpy you see .. 'cos it's always an uneven surface .. and the tyres .. they are sort of rough .. and they have kind of crannies .. that grip on the bumps of the road .. and slow down the bike .. and eventually stop it .. er ..4.. it's also the material of the tyres .. 'cos they are made of rubber you see..

068 **Int** why do you say that about rubber .. /
069 **Da** well .. rubber is rather sticky .. I suppose .. that would increase friction wouldn't it .. / .. 'cos it will be gripping a lot more .. than say wood or something like that ..

(**Da**)'s conceptions of "friction", "gravity" and relevant "surfaces dependent" phenomena, as they appear be in the **Post-I.I.**, or at least as they are interpreted by the researcher, could be represented in a schematic way as follows:

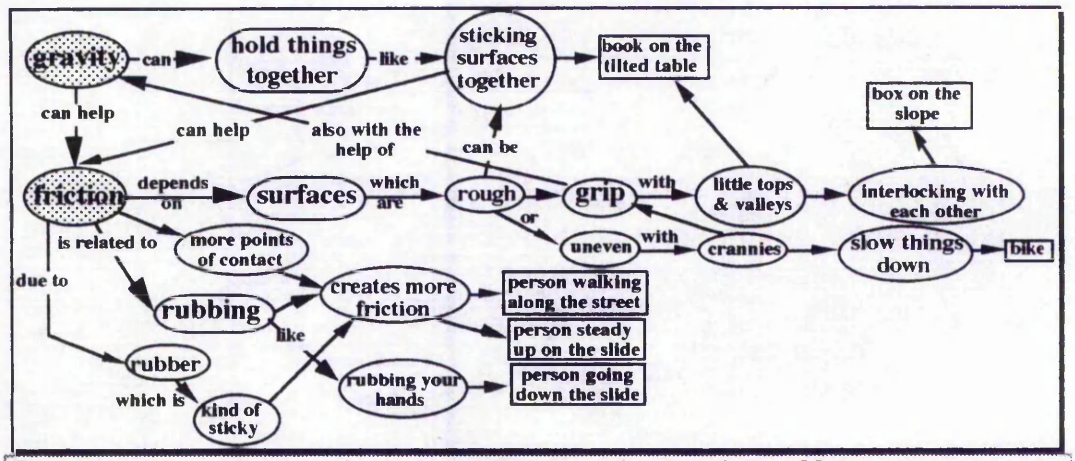


Fig. 4.5.5: A schematic representation of some of (**Da**)'s conceptions from the **Post-I.I.**

On the whole, it seems that his preconception of "gravity" with the attributed frictional characteristics does not appear to act as an "epistemological obstacle", hindering the formation of a new conception of "friction". Thus, "gravity" has maintained its "pulling downwards" characteristic, but a notion of a new characteristic, that of "sticking surfaces together", is added. It is with this characteristic that "gravity" is related to friction as a "helping" force. The new conceptions of "rubbing-related friction" and "surfaces dependent friction" appear to be strongly influenced by the teaching intervention. The latter seems, more likely, to have connections with the preconception of "substances dependent grip" and the ascribed frictional characteristics, that were considered in the **Pre-I.I.**

In (**Da**)'s concept map, "friction" appears to be a central concept (see fig. 4.5.6). It "concerns surfaces" which can be "rough or smooth" and "can interlock", "which means" that their "tops and valleys " get together. This interlocking appears "to be" friction as well. "Friction is made when you slow down", but also "sliding makes

friction". Thus he appears to be consistent with his "surfaces dependent" conception of friction although he does not refer to the role of "gravity" at all. The propositional link between "force" and "friction" seems to be that of "friction includes force" or "force includes friction", which could be probably interpreted as "friction is a kind of force".

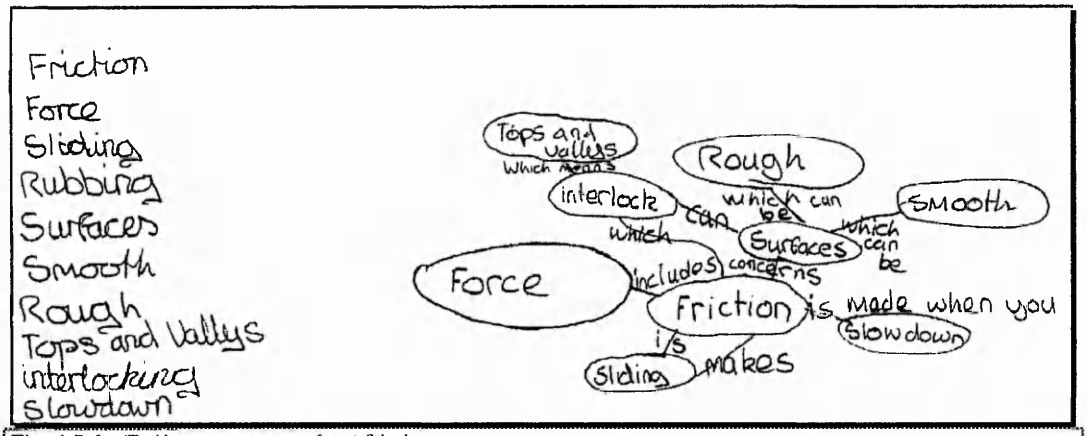


Fig. 4.5.6: (**Da**)'s concept map about friction.

CHAPTER 5

The Study in Greece

5.1.0. Pre-Intervention Interview Analysis (Greece)

As it has already been stated in the previous chapter, the purpose of the pre-intervention interview analysis is to identify, present and interpret groupings of conceptions and alternative conceptions, about frictional phenomena held by the children of this study, before the teaching intervention and within a context of conceptions of "force". The two cards that were added for the study in Greece, are also analysed here. Each card is treated separately, whereas a discussion is written at the end of this analysis.

5.1.a. The card with 'the book on the table' instance

All of the children (**Ge, Ba, Ni, Jn, Geo, Bi, Nt, Ka, Joh, Di**) appear to be recognising the "force of weight" of the book and the table. Only one child (**Di**) though, discusses a conception of "action" and "reaction" between the book and the table. The rest of the children do not recognise any force from the table towards the book. They appear to be viewing the table mostly as a "supporting medium" without considering that to be a force. The book stays on the table and that seems to be something that happens "naturally", without any exerted force.

Thus, (**Nt**) for example recognises the weight of the book "holding it on the table" and the "weight of the table" (008). She suggests that the table "supports the book and holds it in its place" (010), but she seems rather uncertain to consider it to be a force (012).

008	**Nt**	yes .. for the book .. there is its weight .. which is holding it on the table .. also there is the weight of the table ..
009	**Int**	yeah .. do you think there is any force from the table towards the book that holds it there .. ?
010	**Nt**	er ..6.. yes if there wasn't the table the book wouldn't be able to stay there on its own .. the table is supporting it .. holding it in its place ..
011	**Int**	yes .. and do you think this is a force .. ?
012	**Nt**	umm .. I think not .. I am not sure ..

Likewise, (**Jn**) recognises the "force of weight" of the book and the table (008) but he suggests that "the table is made of hard material" and the book does "not go inside it"

or "doesn't sink into it" (010), but he doesn't consider it to be a force (012). He points out that there are no more forces in this instance, because "there is no force to move or to push" the book or the table (014).

008 **Jn** er .. yes .. there is the force of weight .. of the book and the table ..
009 **Int** I see .. do you think there is any force from the table towards the book .. /
010 **Jn** umm .. no .. the table is made of hard material and .. so the book doesn't go inside it .. it doesn't sink into it ..
011 **Int** do you think this is a force .. /
012 **Jn** er .. no .. it is not a force ..
013 **Int** umm hmm .. do you think there are any other forces here .. /
014 **Jn** no .. because there is no force to move .. or to push the book .. or the table ..

(**Ka**) recognises the "force of weight" of the book and the table, but she suggests that the book remains in its place because "the table is placed on the floor" and "everything holds steady" (010) without moving (012). He doesn't appear to consider any force responsible for that though (014).

009 **Int** do you think there is any force from the table towards the book .. /
010 **Ka** no .. I don't think there is .. the book remains in its place because .. the table is also placed on the table .. er .. and so everything holds steady ..
011 **Int** hold steady .. / what do you mean .. /
012 **Ka** er .. steady .. they don't move ..
013 **Int** umm .. do you think this has to do with some force .. /
014 **Ka** no .. this is not a force .. that's how it seems to me ..

Only one child (**Di**) points out that the book and the table have some weight but he also appears to be holding a conception of "action" and "reaction" forces, which he considers as two different forces (014). Hence, he points out that the book exerts an action on the table and the table exerts a reaction towards the book (010). He also suggests that the same happens with the legs of the table and the ground (012).

008 **Di** er .. when the book is on the table it has some weight .. er.. and the table that is on the earth .. has also some weight ..
009 **Int** I see .. do you think this has to do with some force .. /
010 **Di** er .. the book with its weight remains on the table .. and .. so the book has the action and the table that supports it has the reaction ..
011 **Int** umm hmm .. do you think there are any forces at the point where the legs of the table are touching the ground .. /
012 **Di** yes .. the table with its weight is exerting the action and the earth that is supporting it exerts a reaction ..
013 **Int** are these two different forces .. /
014 **Di** yes ..

Interview Card	*Groupings of conceptions and alternative conceptions*	*NoR*
	• **There is the "force of weight" of the book and the table, but there is no force from the floor towards the legs of the table or from the table towards the book. Everything appears to stay in its place rather "naturally".** • **There is an "action" exerted from the book on the table and from the table on the floor but there is also a "reaction" from the floor and the table respectively.**	*9* *1*

Table 5.1.1: A synopsis of the groupings of conceptions and alternative conceptions from the analysis of the "book on the table" instance with respective numbers of children's responses (*NoR*).

5.1.b. The card with 'the book on the tilted table' instance

All of the children appear to be recognising the "force of weight" of the book and the table, which is pulling them downwards. They do not seem to be considering any force from the table towards the book or from the ground towards the table, apart from the case of (**Di**) that discusses again his conception of "action" and "reaction" forces. Some children even mention the "weight of the box" that "supports" the table form the side that it is lifted a bit higher.

*Most of the children (**Ni, Ge, Ba, Bi, Nt, Jn**) appear to be recognising that the "weight" or the "force of weight" is responsible for keeping the book stationary on the tilted table. Thus, they appear to be ascribing a "frictional characteristic" to their conception of "weight", which somehow "holds", "sticks" or "presses" the book on the surface of the table.*

For example (**Ni**) appears to be thinking in terms of the book being "heavy" (022) and thus, its "weight" prevents it from sliding down, holding it "immovable" on the table (024).

022 **Ni** the book .. as it is heavy .. it holds itself on the table and does not slide .. because it is heavy
023 **Int** what do you mean with this .. /
024 **Ni** well that is ... because it is heavy .. it won't slide down .. its weight is holding it immovable ..

(**Bi**) appears to be regarding that there is a "force" along the area of contact of the book and the table which holds the book stationary (020 & 022). She suggests that this force is probably the "weight of the book" which "presses" the table and "holds" it there (022). This happens also because the table doesn't "sink in", since it is made of "hard" material (024 & 026). Thus, she is also referring to a characteristic of the surface of the table.

020	**Bi**	umm .. yes it has a force holding it ..	
021	**Int**	what do you mean .. /	
022	**Bi**	I think there is a force exerted over here .. because it doesn't fall .. it doesn't slide down the table .. er .. it is probably the weight of the book which presses there and holds it in that place ..	[pointing along the area of contact of the book and the table]
023	**Int**	what do you mean .. it presses there .. /	
024	**Bi**	umm .. to push downwards .. and because the table doesn't sink in .. er .. it remains in its place ..	
025	**Int**	the table doesn't sink in .. is that a force .. /	
026	**Bi**	umm .. no the material of the table .. is hard .. that's what I think ..	

(**Nt**) considers the weight of the book as the main reason for its motionless condition, but she also differentiates between a "heavy" and a "light" book (016 & 017). Hence, a "big", "thick" book which is "heavy", would easily hold on the tilted table, while a "light" one "wouldn't have much weight to press" on the table, or "it wouldn't have much force on it". Consequently it would "press the table less" and probably "slide down" (019).

016	**Nt**	er .. well if the book was big and thick .. then it would be heavy and so .. its weight would hold it easily there .. in its place ..
016.5	**Int**	**>>** umm hmm
017	**Nt**	.. but if the book was light .. then there wouldn't be much weight to press .. er .. to press the table to hold it where it is ..
018	**Int**	why do you think that a light book wouldn't hold on the table .. /
019	**Nt**	er .. because the light book .. er .. does not have much force on it .. that is its weight is a little bit .. so it presses the table less .. er .. and it will probably slide down ..

*Three children (**Joh, Geo, Ka**) appear to be considering that apart form the weight of the book which is "holding" it on the surface of the tilted table, another reason for the motionless condition of the book is that the table is not lifted "high enough" for the book to start sliding, or even because the table is not moved at all (**Ka**).*

(**Geo**) suggests that the reason why the book "stays in its place" is because the table is not lifted "high up" (029 & 030), but also because "its weight presses the table and holds there steady" (032 & 034).

029	**Geo**	yes .. the book .. it's is not lifted very high .. er .. I mean the table is not lifted high up .. and the book stays again in its place ..	
29.5	**Int**	**>>** umm hmm	
030	**Geo**	and it can't move ..	
031	**Int**	do you think there are any forces between the surface of the book and the surface of the table .. /	
032	**Geo**	any force .. / .. er .. yes the force of the book .. that is its weight ..	
033	**Int**	why do you think that the book stays in its place and does not slide down the table .. /	
034	**Geo**	er .. because its weight .. its weight presses the table and holds it there steady ..	

(**Ka**) points out that the book stays motionless on the table because they are both "held steady" (020), but if someone "pushed" the book or "moved the table then the book would start sliding (022). She also suggests that there is a "force" which holds the "table steady" and the book stationary on the tilted table and that force is "the weight" (024).

020	**Ka**	er .. I think that .. er .. the weight of the book is holding it in its place .. and also the fact that the table does not move .. although it lifted high up .. this box is holding it steady .. and so the book is held steady ..	[pointing at the box under the table]
021	**Int**	what do you mean when you say that the book is held steady .. /	
022	**Ka**	if the table was moved .. if somebody pushed it there .. then the book could fall down .. er .. I mean .. if the table was moved .. the book would also be moved .. and it wouldn't be able to hold itself up there .. now it is as if a force is holding it ..	[pointing at the lifted side of the table]
023	**Int**	what force do you think that is .. /	
024	**Ka**	er .. the force that is holding the table steady and the force that the book has .. that is the weight ..	

Only one child (**Di**) appears to be sensing a "force" (018 & 022) which is holding the book in its place, but he suggests that the book would slide if the table was lifted higher (020). He appears to be considering that this "force" has to do with the nature of the surface of the table (022 & 024). Thus, if the table is "wooden" then the book would "grip" on its surface and "hold up there", whereas if the table was made of "plastic laminate" the book would probably slide even if it wasn't lifted higher (026).

018	**Di**	yes there is a force ..	
019	**Int**	what do you mean .. /	
020	**Di**	because for the book to fall .. there must be .. er .. we must lift it a bit higher ..	
021	**Int**	umm hmm .. why do you think that we have to do that .. /	
022	**Di**	because .. even here .. it cannot slide down .. because something must be holding it ..	[pointing at the card]
023	**Int**	what do you think that it is .. /	
024	**Di**	er .. the table ..	
025	**Int**	how do you think that the table holds the book steady in its place .. /	
026	**Di**	er .. it depends from what it is made of .. er .. from wood .. if the table was wooden then .. somehow .. the book grips on it .. and holds up there .. but if it has plastic laminate on here then it may even slide .. even if we don't lift it very much ..	[pointing at the surface of the table]

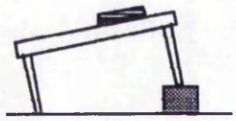
Interview Card	Groupings of conceptions and alternative conceptions	NoR
	• **The "weight" or the "force of the weight" of the book appears to be responsible for its motionless condition on the tilted table, because it somehow "holds", "sticks" or "presses" it there.**	*6*
	• **Apart from this "frictional characteristic" of the weight, the book remains steady because the table is not lifted "high enough" or because "everything is steady".**	*3*
	• **There appears to be a force which is holding the book stationary and it probably has to do with the nature of the surface of the table . Hence, if it is a wooden table then the book would grip more than on a table covered with plastic laminate.**	*1*

Table 4.1.2: A synopsis of the groupings of conceptions and alternative conceptions from the analysis of the "book on the tilted table" instance with respective numbers of children's responses (*NoR*).

5.1.c. The card with 'the man pushing the car' instance

All of the children appear to be recognising the "force from the man" pushing the car and they all claim that he is not strong enough to move the car or that "extra help will be needed" (**Geo, Di**). All of the children are also suggesting that the car is "heavy" and that seems to be another reason for the its motionless condition.

*Five children (**Ge, Ba, Jn, Bi, Ka**) do not appear to be considering any forces at the touching points of the tyres and the ground, apart from the "force of weight" of the car, which is "falling on" those points, holding the car steady. Thus, it appears that they are ascribing a frictional characteristic to the "force of weight", but this doesn't necessarily mean that they are thinking of it in this way.*

Hence, (**Jn**) indicates that there is a force exerted by the man on the car and he suggests that although "we can't see it", "we believe that it exists", just like when a wall is being pushed (029). He points out though, that the car is not moving because the man is "on his own" and "usually cars are heavy" (031). He appears to believe that there is only the "weight" of the car at the touching points of the tyres and the ground and "nothing else" (033).

029	**Jn**	er .. the man is exerting a force to the car .. and that you can't really see .. it doesn't even move anything .. but we believe that it exists .. just like me pushing the wall it will not move but I'll keep pushing it .. and exerting a small force to it ..	
030	**Int**	I see .. why do you think that the car is not moving .. /	
031	**Jn**	er.. because the man is on his own .. and he doesn't have enough force to move it .. and usually cars are very heavy ..	
032	**Int**	do you think there are any forces at the touching points of the tyres and the ground .. /	
033	**Jn**	there .. it is the weight of the car .. which is towards the earth .. nothing else ..	[pointing at the tyres]

(**Ka**) indicates that the car is difficult to be moved because the engine is not working and man "cannot move it on his own", despite the exerted force (029). She considers that the only force at the touching points of the tyres or the man's shoes with the ground is the "weight" (031). But, she points out that the weight is "holding them steady" at their place (033).

029	**Ka**	well .. because the engine is not working .. and it is difficult to move .. err .. also because the car is too heavy .. and the man cannot move it on his own .. umm .. although he is exerting a force ..
030	**Int**	yeah .. do you think there are any other force here ..
031	**Ka**	yes .. there is the force of weight of the car which is touching with its tyres on the ground .. er .. and the weight of the man ..
032	**Int**	do you think there are any forces at the touching points of the tyres and the ground .. / or at the touching points of the shoes of the person and the ground ..
033	**Ka**	no ..4.. I don't think there are any forces there .. er .. only the weight of the car .. and the weight of the person .. holding them steady there .. I think ..

*Four children (**Ni, Geo, Joh, Nt**) appear to be considering that the ground is "supporting" or "holding" (**Nt**) the tyres in their place, but they do not discuss further what this "supporting" can be, or any possible explanation for the phenomenon.*

Thus, (**Joh**) points out that the man and the car are "stepping on the asphalt" (029), which is something "steady" and because this happens, "cars are able to move" (032). He doesn't consider that to be a force though, but he mentions that he has observed it happening this way (034). Nevertheless, he appears to be considering that the ground "supports the car and the man" and somehow "holds" them "steady" (036).

029	**Int**	do you think there are any other forces here .. /
030	**Joh**	umm .. the man and the car are stepping on the asphalt
031	**Int**	hmm .. what do you mean with this .. ./
032	**Joh**	if this didn't happen then the cars wouldn't be able to move .. if they didn't step on something steady .. like asphalt .. er .. it's because they have tyres and they are stepping somewhere steady .. that they can move easily ..
033	**Int**	and .. do you think this is a force .. /
034	**Joh**	er .. no but I have observed it happens this way ..
035	**Int**	do you think there are any forces at the touching points of the tyres and the ground .. /
036	**Joh**	umm .. possibly not .. only the ground supports the car .. and the man .. er .. how to say it .. it holds them where they are .. steady ..

Similarly, (**Nt**) points out the that the "weight" of the man and the car is "held on the road" and it seems that she considers it to be a force (027). She appears to be suggesting that there would be "a force form the car" if it was moving (028), but the man is "not strong enough" and the car is "heavy" that's why it doesn't move (030).

026	**Int**	do you think there are any other forces here .. /
027	**Nt**	yes.. the weight of the car .. which is held by its tyres .. and that's held on the road .. and the weight the man is held on the road .. umm .. I don't see any other forces ..
027.5	**Int**	>> umm hmm ..
028	**Nt**	**ah** .. / .. there would be another force only if the car was moving .. but now .. there isn't .. the force of the car .. because it doesn't move ..
029	**Int**	why do you think that the man cannot move it .. /
030	**Nt**	er .. because he is not strong enough .. he can't exert that much force to move it .. and the car is too heavy .. that's what I think ..

(**Di**) recognises the "weight" of the car and the "weight" of the man (038), but he also points out that the man cannot move the car because it has "more weight" than him, so he will need help (036). He also discusses his conception of "action" being the weight of the car and the person exerted on the tyres and the road respectively and "reaction", being exerted from the ground (040).

036	**Di**	er .. because the man is pushing the car with his forces but .. it has a more weight from the man .. and so it is difficult for him to move it on his own .. he will probably need more people to help him ..	
037	**Int**	I see .. any other forces here .. /	
038	**Di**	umm .. yes .. it is the weight of the man and the weight of the car I just said before ..	
039	**Int**	do you think there are any forces at the touching points of the tyres with the ground .. /	
040	**Di**	yes .. because there at the tyres .. and at the shoes of the person .. an action is exerted .. er .. from the weight .. and a reaction is exerted from the earth ..	[pointing at the tyres and the shoes]

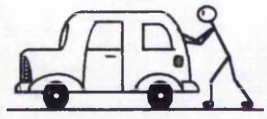
Interview Card	*Groupings of conceptions and alternative conceptions*	*NoR*
	• **The "force of the weight" of the car is "falling" on the tyres of the car which are touching the ground "holding the car steady ".**	*5*
	• **The ground is "supporting" or "holding" the car in its place, but it is not explained how this happens.**	*4*
	• **There is an "action" from the weight of the car and the weight of the man and there is a "reaction" from the earth at the respective points of contact.**	*1*

Table 5.1.3: A synopsis of the groupings of conceptions and alternative conceptions from the analysis of the "man pushing the car" instance with respective numbers of children's responses (*NoR*).

5.1.d. The card with 'the children playing with the tennis ball' instance

All of the children appear to be considering the "force" of the child "on the tennis ball", which is making it move through the air, from one child to the other. Thus they appear to be regarding that there is a force acting upon the ball in the direction of its movement (cf. Watts, 1983b). Furthermore, all of the children seem to be recognising the "force of weight of the children" and the ground which is "supporting them", but they do not regard this to be a force. Strangely enough, none of the children refers to the air as a retarding medium in the movement of the tennis ball.

*Five children (**Ba, Bi, Di, Ka, Geo**) seem to be regarding that, apart from "the force from the child", there is also the force of weight, when the tennis ball is moving in the air.*

Thus for example, (**Bi**) is indicating that "the force from the child" appears to be transporting the tennis ball from one side to the other. Thus, she considers that it has "moving force" (045). She also appears to be recognising the force of "weight" of each child (047), but she suggests that there is no force from the ground towards the children, because "the ground doesn't have any force" (049).

045 **Bi** er.. yes .. it's the force from the child .. that has thrown it and it is going .. almost straight .. to the child over the other side .. so it has a moving force .. umm ..4.. also the weight the ball has ..
046 **Int** I see .. do you think there are any other forces here .. /
047 **Bi** umm .. yes the weight each child has .. which is toughing the earth .. the ground ..
048 **Int** is there a force from the ground to the children .. /
049 **Bi** no .. because the ground doesn't have any force ..

*Four of the above children (**Geo, Ka, Ba, Di**) appear to be considering the weight of the tennis ball when it is in the air. But, they also point out that it goes over the other side and not towards the ground because there is "more force" from one child pushing it over to the other child and not immediately towards the ground.*

For example (**Ka**) points out that the children "are giving a force" to the ball which makes it "move forward", otherwise that ball "wouldn't move on its own" (039). She suggests that when the ball is in the air, it has the "force of the child" and its "weight",

but "because the force form the child is greater, it goes more over to the other side" and "less towards the ground" (041).

039 **Ka** yes .. the way the children are throwing the ball .. they are giving a force to it .. which makes it move .. er .. to move forward .. whereas if they didn't throw it .. if they didn't give it that force .. then the ball wouldn't move on its own .. to go from one child to the other ..
040 **Int** when the ball is in the air .. do you think there are any forces exerted .. /
041 **Ka** er .. it is the force of the child who threw it .. umm .. and its weight .. but because the force from the child is greater .. it goes more over to the other side .. and less towards the ground ..

Similarly, (**Ba**) appears to be recognising the force that the child is "exerting" to the ball and the "weight" of the ball. But since the "force" that the child is "giving" to the ball "is greater", it goes "over to the other side" and not downwards, "only a little bit in the end" (037).

035 **Ba** er .. there is the force that the child is exerting when she throws the ball ..
036 **Int** do you think there is any other force at the ball .. /
037 **Ba** er .. also its weight .. but with the force the child is giving to it .. which is greater .. it goes over to the other side and not downwards .. er .. only a little bit in the end ..

*Two children (**Ni, Jn**) appear to be pointing out that the tennis ball has "some" weight when it is in the air or it has "a bit" of weight because it is in the air.*

Thus, (**Ni**) also recognises the "force of the child", but she suggests that the ball has "weight", because "if it wasn't heavy" the child wouldn't be able to throw it "easily" (038 & 040). She points out though, that the ball has "some weight" which appears to be different from its weight "when you hold it in your hand" for example. In the depicted instance, she suggests that the weight f the ball is "a bit less" because it is "in the air" (042).

038 **Ni** er .. the force from the child helps it to move .. also .. it has weight .. because if it wasn't a bit heavy .. it wouldn't be thrown easily ..
039 **Int** now that the ball is in the air.. do you think there are any forces exerted to it.. /
040 **Ni** er .. the force that the child has given to it .. in order to move .. to go high .. er .. and it also has some weight ..
041 **Int** what do you mean .. also some weight .. /
042 **Ni** when you hold it in your hand .. it has weight .. but here that it is in the air.. it also has weight .. but a bit less .. because it is in the air ..

Likewise, (**Jn**) appears to be relating the "weight" of the ball with the direction of its intended motion. Thus if the ball is thrown upwards, "it has a lot of weight", whereas

if it is thrown "with a straight forward force" it has some weight, "but less" because "it doesn't throw all of its weight that way" (041).

041 **Jn** er .. when the ball is in the air .. umm ..4.. it also has some weight in the air .. it has .. but we throw it with a straight forward force .. to the child opposite .. whereas if we threw it upwards .. the ball would have a lot of weight .. but we now throw it straight ahead .. and it also has some weight .. but less .. because we are throwing it straight ahead and it doesn't throw all of its weight that way

*Three children though (**Ge, Nt, Joh**), do not appear to be considering that the tennis ball has "weight" when it is in the air. Somehow it appears to be losing its weight in the air or the force of weight does not appear to be exerted any more.*

Thus, (**Nt**) seems to be regarding that the child "has given a force" to that ball and it keeps moving "with" that force (038). She suggests though, that the ball doesn't have any weight because "it is in the air" (040) and she ascribes the downwards direction at the end of its trajectory to the same force which becomes "less", causing this effect (042).

038 **Nt** since the child is throwing the ball .. the ball keeps moving .. with the force that it has .. the one that the child has given to it ..
039 **Int** does the ball have weight when it is in the air .. /
040 **Nt** no it doesn't have ,. because it is in the air ..
041 **Int** why then is it going a bit downwards when it reaches the other child .. /
042 **Nt** er .. because the force that the other child has given it becomes less.. that's the force that it had from before .. which made it move ..

In a similar way, (**Ge**) appears to be suggesting that the ball has some weight when "you have it in your hand" (051), but when it is in the air, that force, does not seem to be exerted any more (053). He points out that the only force in that case is the one exerted to the ball "from the child" (053).

051 **Ge** er .. the ball has some weight .. when you have it in your hand .. you can feel it ..er ..
052 **Int** now that it is in the air .. /
053 **Ge** umm .. there is not that force now .. because in the air it only has the force of the child .. or the force from the child ..

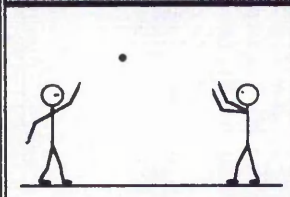
Interview Card	*Groupings of conceptions and alternative conceptions*	*NoR*
	• **There is the force from the child and the force of the weight on the tennis ball.**	*5*
	• **there is more force from the child and that's why the ball goes over the other side and not downwards.**	*4*
	• **The tennis ball has "some" or "a bit" of weight when it is in the air.**	*2*
	• **There is "no weight" or the force of weight does not appear to be exerted any more when the ball is in the air.**	*3*

Table 5.1.4: A synopsis of the groupings of conceptions and alternative conceptions from the analysis of the "children playing with the tennis ball" instance with respective numbers of children's responses (*NoR*).

5.1.e. The card with 'the person dragging the chair' instance

All of the children appear to be considering the force exerted by the child who is dragging the chair along the floor. This is mainly a muscular force, exerted by the "hands and legs" of the child. The weight of the chair and the weight of the person are also forces which are recognised by all of the children. Most of the children are considering the support from the ground on the child and the chair, but they do not seem to regard it as a force.

Thus for example (**Geo**) appears to be recognising the force from the child pulling the chair, the weight of the chair (058) and the weight of the child (060), but he does not consider any other forces on the child or the chair coming from the ground (062).

058 **Geo** the child that is pulling the chair .. that's a force .. the chair that has weight .. and its weight is touching the floor .. I don't think there is any other force ..
059 **Int** do you think there is any force from the floor towards the child .. /
060 **Geo** the child is walking along the floor .. I don't see any force there .. apart from his weight .. I don't think there is any other force ..
061 **Int** do you think there is any force from the floor towards the chair .. /
062 **Geo** the chair .. it's being dragged on the floor .. the child is dragging it .. it doesn't have any other force .. apart from that of the child .. that is pulling it with his hands ..

Similarly, (**Ni**) recognises only the force from the child pulling the chair (046), the weight of the child and the weight of the chair (048). She does not appear to be considering any forces from the ground towards the chair or the child (050).

046 **Ni** er .. the child that is pulling the chair is exerting a force .. because he can pull the chair ..
047 **Int** any other forces here .. /

048 **Ni** yes .. the child has weight .. the chair has also weight .. er ..4..
049 **Int** do you think there is any force from the ground towards the chair .. / .. or the child .. /
050 **Ni** no .. I don't think so .

*Four of the children (**Bi, Ka, Joh, Jn**) appear to be suggesting that the weight of the chair is somehow "split" or "divided" between the pulling force of the child and the floor that is supporting it, or the floor takes "some" (**Joh**) or "most" (**Ka**) of the weight of the chair, making it easier for the child to drag it. Most of the children though, (**Bi, Ka, Joh, Jn, Joh, Di**) appear to be suggesting that the chair is moved easier when it is dragged instead of lifted. Hence, rather intuitively, or by using everyday experience, they appear to have the view that things are moved easier when they are dragged or slid instead of lifted, because despite the caused friction, not all of the weight is lifted.*

Hence, (**Bi**) indicates that there is a force exerted from the child on the chair (053). She also recognises the force of weight of the chair and the child (055) and she suggests that it would be easier for the child to drag the chair, instead of lifting it up, because its weight is "divided between the pull of the child and the ground" (057). On the other hand, if the child lifts it up, he/she will "take all of the weight" (057).

053 **Bi** yes .. the child must exert a force with her hands and legs .. to pull the chair ..
054 **Int** I see .. any other forces here .. /
055 **Bi** the force from the chair .. I mean its weight .. which is touching a bit there .. umm ..4.. its also the weight of the child .. [pointing at the points that the legs of the chair are touching the floor]
056 **Int** if the child lifts up the chair .. instead of pulling it .. to move it .. will that be easier for the child .. /
057 **Bi** it would be easier for the child now that he is dragging it .. because he is dragging a bit of its weight .. because it is divided between the pull of the child and the ground .. and so it will be easier .. but if he lifts it up .. then he will take all of his weight .. and it will be more difficult for him ..

Likewise, (**Ka**) recognises a "moving" force from the child (049), the weight of the chair and the weight of the child (051). She suggests that it will be more difficult for the child to lift the chair in order to move it instead of dragging it along the floor. In the latter case, the floor appears to be helping her (053). This is because "most of the weight" is lifted by the floor, whereas if the chair is lifted with the hands a lot more force will have to be exerted (055).

049	**Ka**	yes .. I think that a moving force is exerted by the child .. who is trying to move the chair somewhere else .. a bit further ..
050	**Int**	I see .. do you think there are any other forces here .. /
051	**Ka**	yes .. the weight that the child has .. and the weight of the chair that is touching the floor ..
052	**Int**	when do you think that the child will exert more force .. / when she is lifting the chair to move it or when she is dragging it just like now ..
053	**Ka**	er .. when she is going to lift it .. because then she will lift all of its weight .. whereas now the floor is helping her ..
054	**Int**	what do you mean .. /
055	**Ka**	because the chair is touching the floor .. the child is not exerting a lot of force .. to pull it .. because most of the weight is lifted by the floor.. but she is going to lift it with her hands she will have to exert a lot more force .. of course ..

Similarly, (**Jn**) suggests that the child would exert a greater force if the chair was lifted up (050) and thus, "the magnitude of the force that the child is exerting to lift the chair will be greater". On the contrary, when the chair is dragged not all of the weight is pulled and it becomes easier for the child to move it. He also indicates that if the ground has "pebbles", then it will be more difficult for the chair to be dragged, just like on the beach, but he does not explain why that happens (053 & 055).

050	**Jn**	umm .. the child would exert a grater force if she lifted the chair .. and this is because .. then she is lifting all of the weight of the chair and it is heavier that if she is dragging it .. because then she is not lifting all of its weight ..
050.5	**Int**	>> umm hmm ..
051	**Jn**	that is the magnitude of the force that the child is exerting to lift the chair will be greater .. than when she is trying to drag it ..
052	**Int**	I see .. do you think there are any forces at the touching points of the chair with the ground .. /
053	**Jn**	umm .. no .. only some of the weight of the chair .. that is touching the ground is there .. but is the ground has some pebbles .. then it is more difficult to pull the chair ..
054	**Int**	do you think there is any force there then .. /
055	**Jn**	no .. but it has happened to me when I pull a chair on the beach ..

Only (**Di**) seems to be regarding an "action" from the legs of the child because "he is walking" and an "action" from the chair on the ground. He also considers a "reaction" from the ground towards the chair, because "it is also moving" (066). Thus, he appears to be thinking of "action" as a force related to movement (068). He suggests though, that it will be easier for the child to drag the chair instead of lifting it. This is because "the earth is exerting a reaction force" to the weight of the chair and he claims that it "helps the child" (070).

066	**Di**	well .. with his legs there is an action .. and the earth has a reaction .. because here he is walking .. er .. also the child has a force with his hand .. he is pulling the chair .. but also the chair has an action on its leg and the earth has a reaction .. because it is also moving ..
067	**Int**	where the child is pulling the chair ... what force do you think there is .. /
068	**Di**	umm .. it's the action because .. it is helping it to move ..

069 **Int** I see .. when do you think that the child is exerting more force .. now that she is dragging it .. or when she is lifting it up .. to move it .. /

070 **Di** er .. now that she is dragging it .. because when she is lifting it up .. she is lifting all of it weight .. so she will have to exert a greater force .. whereas now .. the earth is exerting a reaction force to its weight *(chair)* and that helps the child ..

Interview Card	*Groupings of conceptions and alternative conceptions*	*NoR*
	• **The weight of the chair is "split" or "divided" between the pulling force of the child and the floor which takes "some" or "most" of the weight.**	*4*
	• **Most of the children appear to be suggesting that the chair is moved easier when it is dragged instead of lifted.**	*7*
	• **There is an "action" from the chair towards the ground, which appears to be related to the movement of the chair and there is a "reaction" from the ground towards the chair, which "helps the child" to move it.**	*1*

Table 5.1.5: A synopsis of the groupings of conceptions and alternative conceptions from the analysis of the "child dragging the chair" instance with respective numbers of children's responses (*NoR*).

5.1.f. The card with 'the parachute' instance

All of the children appear to be recognising the force of weight of the box, which is pulled downwards due to gravity and the weight of the parachute, although they suggest that it is "not much". They appear to be considering a force from the air which is pulling the parachute upwards and most of the children (**Ge, Ba, Ni, Bi, Geo, Nt, Ka, Joh**) point out that it "pumps up" the parachute and consequently it is retarding its descent .

Hence, (**Joh**) for example, points out that the parachute "is getting air inside", which "pumps it up" and as a result the parachute comes slowly down, or it can "hold in the air" (060). He also recognises the weight of the box and "a bit of weight that the parachute has". They are both pulled downwards by the "earth", whereas "the force of the air" is pushing the parachute "upwards" (062) and he suggests that without the parachute the box would be destroyed (064).

060 **Joh** the parachute is getting air inside .. and as it goes down .. and the air is getting inside it .. it pumps it up .. and so it can hold in the air .. the box with the drugs and the food ..

061 **Int** I see .. any other forces here .. /

062 **Joh** er .. the weight of the box .. and a bit of weight that the parachute has .. the earth is pulling them down .. er .. and the force of the air that is pushing the parachute upwards .. and so it holds it more in the air ..
063 **Int** do you have anything else to add here .. /
064 **Joh** umm .. if the parachute didn't exist .. the box would fall down with a great force .. and the food and medicines would spread all over the place .. we would have a very bad landing .. *(laugh)*

Similarly, (**Ka**) appears to be recognising the weight of the box and the weight of the parachute, "although parachutes are light" they still have some weight (063). She points out that "the force of the air" makes the parachute move slowly towards the earth (065) because it is pushing it upwards and it "pumps it up" like "a balloon" retarding it descent . She suggests that if the air didn't exist then the parachute "would come straight down" damaging the box and its goods (067).

063 **Ka** yes .. the box has weight .. but also the parachute has some weight .. although parachutes are light .. it has some weight though ..
064 **Int** I see .. why do you think that the parachute is going lowly downwards .. /
065 **Ka** it is .. the force of the air .. which makes it move slowly towards the earth ..
066 **Int** what doe you men when you say .. the force of the air .. /
067 **Ka** it is giving it air .. it pumps it up .. like a balloon .. er .. it is getting inside it and it is like pushing it upwards .. and so it comes slowly down the earth .. whereas if the air didn't exist ..then the parachute would come straight down .. it wouldn't fall nicely and the things would be damaged .. and they will never reach their destination ..

Also, (**Geo**) seems to be considering "the force of weight" of the box and the parachute (080) and points out that the air is retarding the downfall of the parachute (082). This is because it "is getting" inside the parachute and "it pumps it up" and that holds it in the air, following the direction that the wind is blowing (084).

080 **Geo** yes .. the box has the force of weight .. and this is pulling it straight downwards .. that is if it didn't have the parachute .. which also has some weight .. it would fall down and break ..
081 **Int** how do you think that the parachute is going slowly downwards .. /
082 **Geo** er .. as the air is getting inside it ..inside the parachute .. it can't fall down quickly ..
083 **Int** why do you think this happens .. /
084 **Geo** er .. it works with air .. always .. and the air is getting inside it and it pumps it up .. and that holds it up .. and it goes wherever the wind is blowing .. so if the wind blows south .. it will go south ..

Nevertheless, (**Jn**) appears to be thinking in terms of air "passing through" the parachute, slowing down its "impetus" (063), which the parachute seems to have gained due to the downwards pulling force of the weight of the box (061 & 063)

061 **Jn** the box with the food and medicines has some weight and so with this weight it falls towards the earth .. with the parachute .. this is a force .. it is gravity .. that is exerted from the earth .. because the box and the parachute are constantly changing place .. they are moving ..

062 **Int** I see .. why do you think that it goes slowly towards the ground .. /
063 **Jn** er .. with the parachute .. as it goes down .. the air that is passing through it .. slows down its impetus .. the impetus of the weight of the box as it goes down

(**Di**) also indicates the weight of the box and the parachute (076) and suggests that the air is getting inside the parachute and it is being held in there retarding its descent (078). Furthermore, he appears to remain consistent with his conception of an "action" which seems to be exerted by the weight of the box and a "reaction" exerted by the "strings" of the parachute, which look as if they are "pulling in the opposite direction" (080).

076 **Di** er .. it's the weight of the box.. and the force of the parachute which is holding the air inside it .. and the box doesn't fall straight down ..
077 **Int** what do you mean .. / how does it hold the air .. /
078 **Di** er .. as it falls downwards .. the air is getting inside the parachute .. and it is as if it is pushing it upwards .. and it is holding it in the air .. and so it goes slowly towards the ground .. er .. it holds the air inside it and it doesn't fall quickly .. with great force ..
079 **Int** I see .. any other forces here .. /
080 **Di** umm ..4.. there with the strings .. it is as if .. the box with its weight has an action and the parachute .. it is as if it is pulling it in the opposite direction .. and so there is a reaction ..

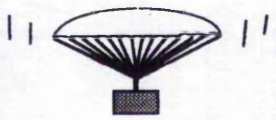
Interview Card	*Groupings of conceptions and alternative conceptions*	*NoR*
	• **The force of the air is pushing the parachute upwards retarding its descent.**	*10*
	• **it is as if the air "pumps up" the parachute slowing it down.**	*8*
	• **The air is passing through the parachute slowing down the "impetus" that it has, due to the pulling force of gravity.**	*1*
	• **There seems to be an "action" exerted by the weight of the box and a "reaction" exerted by the "strings" of the parachute that appear to be "pulling in the opposite direction.**	*1*

Table 5.1.6: A synopsis of the groupings of conceptions and alternative conceptions from the analysis of the "parachute" instance with respective numbers of children's responses (*NoR*).

5.1.g. The card with 'the slow-down of the bicycle' instance

All of the children appear to be recognising the "force of weight" of the child and the bicycle, which are both pulled downwards. The ground, which is "supporting" their weight, is not considered to be exerting a force. Thus, the only force they appear to be recognising at the touching points of the tyres of the bicycle and the ground, is the

"force of weight", which "falls onto" the tyres . Nevertheless, they do not appear to think of "weight" as a "force" that "has to do with" the slow-down of the bike.

*Hence, five children (**Ge, Ba, Ni, Jn, Geo**) appear to be indicating that the main reason for the deceleration of the bike is that "the child is not pedalling any more", or "no more force is exerted by the child".*

(**Ge**) seems to be recognising "exerted forces" on the tyres of the bike when it "goes" (080), but he does not clarify their nature. He points out that the bike will stop "somewhere", as soon as the child stops exerting "some force on the pedals" (082 & 084). The "weight" of the child and the bike is the only force that he appears to be considering at the touching points of the tyres and the ground (086 & 088).

080	**Ge**	there are forces exerted on the bike with its tyres .. that is .. when it goes on the road .. its tyres are moving and so it goes ..
081	**Int**	yes .. but here .. the bike is moving slowly and soon it is going to stop .. why do you think that it is going to stop ..
082	**Ge**	in a while .. because the child is not pedalling .. somewhere .. sometime .. it is going to stop .. whereas if the child continued to pedal it wouldn't stop and it would keep going ..
083	**Int**	do you think that the bike will stop because the child will stop pedalling .. /
084	**Ge**	yes because the child is exerting some force on the pedals and it makes the bike move .. as soon as it stops .. the bike will stop ..
085	**Int**	I see .. do you think there are any forces here .. /
086	**Ge**	yes .. the weight of the bike and the weight of the child .. on the tyres which are touching the ground ..
087	**Int**	do you think there are any forces at the points that the tyres are touching the ground .. /
088	**Ge**	er .. no I don't think so .. the bike .. the tyres are going round on the road .. there is no force there though ..

(**Jn**) appears to be thinking in terms of "the impetus" that the child "has given" to the bike to make it move (069) and he suggests that since the child is not pedalling any more the bike gradually "looses its impetus" (071), which means that there is no more "force exerted by the child" (073). he also recognises the weight of the child and the bike exerted at the touching points of the tyres and the ground and he suggests that the ground is supporting them. He mentions that because the ground is "asphalt", it supports the bike rather "easily", whereas if it was sand, it "would sink in" (075).

069	**Jn**	it is the impetus that the child has given it .. ever since he pedalled ..
070	**Int**	yes .. but now the child has stopped pedalling can you explain why .. it slows down and eventually it is going to stop .. /
071	**Jn**	umm .. because the child is not pedalling any more .. she is not exerting any more force with her legs to move it .. and so it gradually loses its impetus ..

072 **Int** what do you mean loosing its impetus .. /
073 **Jn** er .. it's loosing the force that the child has given to it .. who is not pedalling any more
074 **Int** I see .. do you think there are any forces at the touching points of the tyres with the ground .. /
075 **Jn** no .. only the weight of the bike and the weight of the child are pressing there .. and the ground is supporting them .. easily .. because it is asphalt .. if it was sand .. it wouldn't move easily because it would sink in ..

*Two children (**Joh, Ka**) appear to be considering that the bike stops because the child stops pedalling and consequently the bike runs out of "mechanical energy" or "a kinetic force". Although they are referring to such terms, they quite possibly mean that the bike is running out of "a moving agent" which makes it decelerate.*

Thus, (**Joh**) points out that the "mechanical energy" from the "pedals and the chain" will gradually "run out" and as a consequence the bike will stop moving (073). The weight of the bike and the child is the only force he recognises at the touching points of the tyres and the ground, which "falls on them" (075).

073 **Joh** it will stop .. because the mechanical energy that the pedals and the chain have .. will run out gradually and so the wheels won't be able to move and the bike will stop sometime ..
074 **Int** I see .. do toy think there are any forces at the touching points of the tyres and
075 **Joh** the ground .. /
er .. that's where the weights of the child .. and the bike .. falls on them .. umm .. I don't think there is any other force ..

Likewise, (**Ka**) appears to be suggesting that because the child is not pedalling any more, there is no more "kinetic force" to keep the bike going and it will stop somewhere (071). She also considers the weight of the bike and the child as the only force on the tyres (073).

071 **Ka** er .. the bike will stop because the child is not pedalling any more ..and then the bike .. will not have a kinetic force any more .. to move it er .. and it will stop going in a while ..
072 **Int** do you think there are any forces at the touching points of the tyres with the ground .. /
073 **Ka** no there are no other forces there .. apart form the weight of the child and the weight of the bike ..

*Two children (**Bi, Nt**) appear to be thinking in terms of a "surface effect" that the road might have for the slow-down of the bike. It seems to be a characteristic of the surfaces, or of the nature of the road and they do not really consider it to be a force.*

Hence, (**Bi**) points out that if the road is "bad" or has "potholes" (079), then the bike will stop "a lot faster", because "the tyres are getting into the potholes" and that appears to be "hindering" the motion of he bike (081). She doesn't seem to consider that to be a force, although she mentions that "it is something like a force" which makes the movement of the bike difficult (083).

078	**Int**	do you think there are any forces at the touching points of the tyres with the ground .. /
079	**Bi**	no .. I don't think so .. er ..4.. only when the road is bad .. and it has potholes
080	**Int**	what will happen then .. /
081	**Bi**	er .. the bike is going to stop a lot faster .. because the tyres are getting into the potholes and they are hindering its motion
082	**Int**	and .. do you think it is a force .. /
083	**Bi**	umm .. it is something like a force .. how can I say it .. it makes it difficult for the bike to move ..

Similarly, (**Nt**) appears to be considering the nature of the surface of the road as a hindrance in the motion of the bike. Thus, if the bike is moving on a "dirt road", it will stop faster, whereas if it is moving on the "asphalt" it "will go a bit further" (073). She does not consider that to be a force though (075).

072	**Int**	do you think there are any forces at the touching points of the tyres with the ground .. /
073	**Nt**	umm .. maybe .. if we .. say that the road was .. a dirt road then the bike would stop a lot faster .. whereas on the asphalt it would stop later .. it will go a bit further ..
074	**Int**	do you think that this has to do with any force .. /
075	**Nt**	er .. probably not .. it has to do with the road the bike moves on .. that is not a force really ..

(**Di**) points out that apart from the child who stops pedalling, "the earth does not let" the bike "move freely" (092). Thus, he is the only child who seems to be thinking in terms of "rubbing" tyres on the surface of the ground which are retarding the motion of the bike (094). He does not consider it to be a force, but rather intuitively, he suggests that if the road has "stones or potholes" the bike will stop faster (096).

091	**Int**	I see .. in this case the bike goes slowly and sometime it is going to stop .. why do you think that happens .. /
092	**Di**	because the child stops pedalling and .. since he is not using the brakes .. then the bike will stop slowly on its own .. but also because the earth does not let it move freely ..
093	**Int**	what do you mean .. the earth does not let it move freely .. /
094	**Di**	er .. it is because the tyres of the bike are rubbing on the ground .. and it won't go any further .. it might run into a stone and stop suddenly .. or it might even fall down ..
095	**Int**	I see .. do you think this has to do with any force .. /
096	**Di**	umm .. no .. it looks like this to me .. and if the road has stones or potholes .. then it will stop a lot faster ..

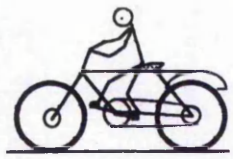
Interview Card	Groupings of conceptions and alternative conceptions	NoR
	• **The bike slows down and will soon stop moving because the child "is not pedalling any more" or there is "no more force exerted" by the child.**	*5*
	• **The bike will stop moving because there is no more "mechanical energy" or "kinetic force".**	*2*
	• **The surface of the road might effect the slow-down of the bike. Thus if the road is "bad" or has "potholes" it is hindering the motion of the bike.**	*2*
	• **The ground does not let the bike move freely because the tyres are rubbing on its surface retarding its motion.**	*1*

Table 5.1.7: A synopsis of the groupings of conceptions and alternative conceptions from the analysis of the "slow-down of the bicycle instance" instance with respective numbers of children's responses (*NoR*).

5.1.h. The card with 'the skateboard' instance

All of the children appear to be recognising the "force of weight" of the child and the skateboard which is pulling them downwards, "pressing" the wheels onto the ground.

*Five children (**Ba, Jn, Bi, Nt, Ka**) appear to be suggesting that the skateboard will slow down and stop because "the child is not pushing any longer" or "the child is not exerting any more force". Furthermore, they appear to be viewing that force as a moving agent for the skateboard, which stops "existing" when the skateboard stops moving, or the other way round.*

Hence, (**Ba**) for example points out that since the child "is not giving" any more force to the skateboard, it is going to slow down and "stop soon" (084).

083 **Int** why do you think that the skateboard goes down slowly and it will stop sometime .. /

084 **Ba** er .. because the child is not giving it any more force .. because she is not pushing with her leg .. so there is no more force to move it ahead .. er.. so it's probably going to stop soon ..

Likewise, (**Jn**) indicates that if the force exerted by the child "stops existing" (084), because the skateboard "is loosing it gradually" (086), then it will stop moving. He recognises the weight of the child and the weight of the skateboard (086), but he doesn't think that there are any forces at the touching points of the wheels and the ground (088).

084 **Jn** er .. yes .. there is a force which is the force that the child is giving to the skateboard with his leg .. when he is pushing it .. er .. this force stops existing when the skateboard stops moving
085 **Int** I see .. do you think there are any other forces here .. /
086 **Jn** umm .. apart from that force that the skateboard has and which it is loosing gradually .. it is the weight of the child and the weight of the skateboard which is touching the earth ..
087 **Int** do you think there are any forces at the touching points of the wheels with the ground ..
088 **Jn** umm .. no I don't think there are any forces there ..

*Four children (**Ge, Ni, Geo, Di**) appear to be considering that the weight of the child and the skateboard is "pressing" or "pushing" on the ground, or on the wheels, and in that way, it is hindering its motion. This is seen in combination with the fact that the child is "not pushing any more". Thus, they seem to be attributing a frictional characteristic to "weight", which effects the slow-down of the bike.*

Hence, (**Ge**) points out that the skateboard will stop soon because there will not be any more pushing force from the child (092). But, he is also suggesting that another reason for the deceleration of the skateboard is that its weight and the weight of the child "are pushing the ground" (094) or "pressing the floor" (096) and hinder the motion of the skateboard. He is also suggesting that the heavier the child is the sooner the skateboard will stop (096).

092 **Ge** er .. because he is not pushing any more with his leg .. the skateboard is going to stop soon..
093 **Int** can you explain why this happens .. /
094 **Ge** because .. with the weight that the skateboard has .. and the weight of the child .. they are pushing the ground and make it gradually stop ..
095 **Int** how do you think that this happens .. /
096 **Ge** well .. let's say .. my weight is pushing down since I am not pushing any more .. my weight is pressing the skateboard .. which is pressing the floor .. and it stops .. if there was somebody heavier than I am .. then it would stop faster ..

Likewise, (**Ni**) is indicating that the skateboard will stop moving when there "is no more force" from the child (078), but she is also ascribing a "frictional characteristic" to the "weight" of the child and the skateboard, which "is pressing the wheels", which in their turn "are pressing the ground" and that slows down the bike (080). She suggests that the heavier the child is the "sooner and easier" the skateboard will stop (082).

077 **Int** and when the child stops pushing .. / what will happen .. /
078 **Ni** er .. then .. there is no more force and it will stop going ..
079 **Int** do you think there are any forces at the touching points of the wheels and the ground .. /

080 **Ni** er .. only the weight .. the weight of the child and the skateboard .. which is touching on the skateboard .. and that is touching .. and pressing the wheels .. which are pressing the ground .. and that slows it down ..
081 **Int** I see .. anything else you want to add here .. /
082 **Ni** er .. yes .. the heavier the child is the sooner and the easier the skateboard will stop ..

*Two children (**Bi, Ka**) appear to be suggesting that the nature of the surface of the road may have an effect on the motion of the skateboard.*

(**Bi**) points out that if the road has "potholes" then "it will be dangerous for the child" but also the skateboard will stop a lot faster (091). She does not seem to consider that to be a force though (091).

090 **Int** do you think there are any forces at the touching points of the wheels and the ground .. /
091 **Bi** no .. except if .. like the bike .. if there are potholes on the road .. then it will be dangerous for the child .. er .. and he will stop a lot faster .. but again this is not a force .. I don't know ..

Similarly, (**Ka**) suggests that if the ground is "uneven" then the skateboard will "stop a lot faster", because it looks as if the surface of the ground is "holding it back in a way". If the skateboard is on the "asphalt", which is "flat" then it will probably "go further" (083).

082 **Ka** do you think there are any forces at the touching points of the wheels of the skateboard and the ground .. /
083 **Int** er .. only if the ground is uneven .. and not flat like asphalt .. it will go further .. then the skateboard will stop a lot faster .. because the ground is holding it back in a way ..

Only (**Joh**) appears to be considering the role of the "force of the wind" (090) in the motion of the skateboard. Thus, if the wind is blowing from the back of the person, then it will give him/her "mechanical energy" and the skateboard will move further. On the other hand, if it is blowing in the opposite direction the skateboard will "stop a lot faster" (088).

088 **Joh** well .. also when the wind is blowing .. from behind of him .. it is giving him mechanical energy .. and he will go a bit further .. whereas if the wind is blowing from the front .. the skateboard will stop a lot faster ..
089 **Int** do you think this is a force .. /
090 **Joh** yes .. it is the force of the wind ..

Interview Card	*Groupings of conceptions and alternative conceptions*	*NoR*
	• **The skateboard slows down and will stop moving soon because the child "is not pushing any more" or there is "no more force exerted" by the child.**	*5*
	• **The weight of the child and the skateboard is "pressing" or "pushing" on the wheels, which are touching the ground and this is hindering the motion of the skateboard.**	*4*
	• **The nature of the surface of the road may hinder the motion of the skateboard and slow it down faster.**	*2*
	• **The wind might also help the slow-down of the skateboard.**	*1*

Table 5.1.8: A synopsis of the groupings of conceptions and alternative conceptions from the analysis of the "skateboard" instance with respective numbers of children's responses (*NoR*).

Discussion

Some children appear to be considering that "gravity" or the "force of weight" is responsible for "sticking" or "holding" things on surfaces. Thus, the "weight" of the book "holds" or "presses" it on the surface of the tilted table, or the weight of the car keeps it steady on the road, despite the push from the man. In this way, a "frictional characteristic" appears to be attributed to the "weight" of these bodies, but it could not be claimed that the children are necessarily thinking of it in such a context. Nevertheless, they appear to be using this conception of weight to explain "frictional phenomena" depicted in the interview cards.

Similarly, in the cases of the *'slow-down of the bicycle'* and the *'skateboard'*, some children appear to believe that the weight of theses bodies is "pressing" or "pushing" their wheels on the surface of the ground and this is hindering their motion. Some children appear to be indicating that the nature of the surface of the road may also hinder the motion of the bike and the skateboard, especially when there is no more "power" or "kinetic force" to keep them going. Thus, if the road is "bad" or has some "potholes" the bike or the skateboard will stop a lot faster. Only (**Di**) appears to be suggesting that apart from the "rough" road, which does not let the bike "move freely", the tyres are also "rubbing" on the surface of the ground, slowing it down faster.

Strangely enough, there is no reference to air resistance in the *'children playing with the tennis ball'* instance. Instead, it is suggested that the tennis ball has "little" or "no weight" when it is in the air. Furthermore they seem to consider that the "force from the child" is exerted upon the tennis ball when it is in the air. All of the children point out though, that the air is pushing the parachute upwards, retarding its descent. Thus, they appear to be viewing "air" as a retarding medium for objects that move through it. Nevertheless, only (**Joh**) seems to be indicating that "the wind" might also "help" the slow-down of the skateboard.

In the person dragging the chair instance most of the children appear to be considering that the chair is moved easier when it is dragged instead of lifted. In this way, they seem to be sensing that, despite the friction caused at the interface of surfaces in contact, things are moved easier when they are dragged on the floor or on the ground. Some of the children seem to attribute this to the weight of the chair, which is divided between the pulling force of the person and the floor that is supporting it.

5.2.0. The Teaching Intervention in Greece

The teaching intervention in Greece was carried out in an E' Grade (Year 5) at a local primary school in Rethimno, Crete. It was a series of two teaching sessions which had been planned by the researcher in collaboration with the teacher, but were mainly taught by the latter. At certain moments the researcher acted as an assistant teacher helping the children in their investigations. For most of the time during the teaching sessions the researcher was sitting in a corner of the classroom, observing what was happening. There were two tape recorders, installed at different corners of the classroom, which were used to record most parts of the classroom debate. Some pieces of children's authentic utterances are presented within speech marks in the teaching sessions that follow.

At the time of this teaching intervention the children were exploring "mechanical phenomena", according to the national science textbook for E' Grade. Thus, before the unit that refers to the force of friction they had been taught about the concept of force an how forces are represented with arrows. They had heard for instance that forces have a point of application, a direction and a magnitude, or that forces can change the shape or the "kinetic condition" of a body. Moreover, they had heard about "action and reaction" and that forces "appear in pairs". Since the beginning of the thematic unit on "mechanical phenomena", not much experimentation was conducted in class, apart from pushing and pulling some objects and "measuring physical strength as a force". Sometimes a force meter was used to measure a "pulling force". The investigation which was organised for the concept of friction, was the first one that the learners did within this thematic unit (cf. § 5.2.1).

Before the two sessions of the teaching intervention are described and presented, there is a reference to and a short analysis of the national science textbooks for the learner and the teacher, followed by a description of the specific classroom setting of this study.

5.2.1. Referring to the "Curriculum", the National Textbooks and the Teaching of Primary Science in Greece.

In Greece there is no such document as "The National Curriculum" for science in the primary school. There is "a form of Curriculum", which has been published in "The Government's Newspaper". It is very brief and it mainly refers to:

- the aims for teaching a certain subject (e.g. science), and
- the framework of General Units, which is split into:
  - intentions or aims of the general units,
  - presentation of sub-units,
  - objectives of each sub-unit, and
  - basic elements of content for each sub-unit

Thus, for example, the "Science Curriculum" for E' Grade (10-11 years) was published in The Government's Newspaper in 1985 (Leaflet No. 140, pp. 2257-2261) and it is still valid today!

The curriculum is mainly put into practice through the national textbooks, which exist for almost all of the subjects, throughout the primary and secondary education. In most of the times they are accompanied by a (national) teacher's book which provides further information about the content and some ideas for teaching and assessing the various units and sub-units of a certain subject. The national textbooks are produced by The Hellenic Pedagogical Institute[1] and they are the same for all of the children, all over Greece, in public and most of the times even in private schools. It has been claimed that the national textbooks have actually replaced the curriculum documents, since teachers very rarely refer to the latter, or seek for some advice from them (Flouris, 1991)[2]. Thus, in the "teacher's book" (1986), which supports the learner's science textbook for E' grade, it is stated that:

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[1] The Hellenic Pedagogical Institute is affiliated to the Ministry of National Education and Religions.

[2] As Flouris (1991) contends "... it is often the case that units which are contemplated in the curriculum, are not fully presented or are completely absent from the textbook which was written for its fulfilment ... the pupil's textbook, which was written to complement the curriculum, actually abolishes it through the book-centred behaviour of the teacher ... the teacher's book which is restricted to methodological clarification and guidelines for

> The aim of the book [the learner's textbook] is to broaden the pupils' interests about the natural world, and to help them develop the skills of observation, experimentation and investigation in order to **understand and assimilate the concepts which are introduced in each teaching unit. The book also aims to develop the creative abilities of the pupils and their critical thinking.** (pp. 5-6, emphasis in the original)

In the Greek primary school, science is introduced as an individual subject, mainly in the fifth and sixth grade (10-11 and 11-12 year-old children respectively), through a two-volume series of national textbooks for each of the two grades respectively. They are entitled "I Investigate the Natural World" and they include information and knowledge from main science disciplines such as physics, chemistry, biology, human biology, geology, etc. Each unit presented in these textbooks, contains verbal definitions of basic science concepts (e.g.: force, work, energy), pictorial and verbal descriptions of simple experiments and/or investigations (e.g.: the measurement of friction for a block of wood which is slid on various table surfaces), brief information about the life and achievements of famous scientists (e.g.: Newton, Archimedes) and at the end of each unit, some questions or problems for self-assessment and/or classroom discussion, usually entitled as "think and answer" or "I check what I learn" (e.g.: *Why do cars slip easily, when the roads are dump or covered with snow?*).

The general units of the first volume of the science textbook for E' Grade are the following four:

A. ***Matter and energy***
B. ***Thermal phenomena and phenomena of light***
C. ***Mechanical phenomena***
D. ***Phenomena of electricity and magnetism***

The C unit which is on "mechanical phenomena" is of particular interest for this inquiry. It has the following sub-units and teaching units:

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the use of the school textbook without promoting the selection of alternative teaching subjects, actually worsens this situation instead of improving it." (p.224).

C_1. Getting to know about forces

1. Forces around you
2. How we represent forces
3. Action and reaction
4. The force of friction
5. Bodies have inertia

C_2. Gravitation of the earth

1. The force of gravity
2. Gravitational forces in space
3. Humans in space

C_3. Work and mechanical energy

1. A force produces work
2. Mechanical energy

The first sub-unit (C_1) presents the general context where the teaching unit "the force of friction" is presented. This is basically the framework of forces being pushes or pulls, which are represented with arrows (vectors), the forces of action and reaction and finally inertia, which is presented as a characteristic of bodies. The predetermined structure of the teaching units within the textbook presupposes that the learners should be taught units 1 to 3 before the get to the fourth one (the force of friction)[3]. Usually, each teaching unit is taught during one teaching hour (approximately 45 minutes). But if teachers wish to extend that period of time they may do so. For instance, they may decide to spend some more time for an investigation, despite the fact that the time limits for the teaching of a unit may seem to be, more or less, fixed. In principle, with such a structured teaching material included in a national textbook, they do not seem to have considerable teaching freedom, but in practice they may develop their own policy and deal with the textbook in their own "creative way", although this is not often the case (Flouris, 1991).

The concept of "the force of friction" is supposed to be "taught and investigated" within one teaching hour, but for the purposes of this inquiry and because of the sensitivity of the teacher in teaching and learning issues, this time was considerably extended in two morning sessions of approximately one hour and twenty-five minutes (1.25') each. Investigations with blocks of wood were part of the unit in the textbook

[3] For a complete presentation and a full translation of the teaching unit "**4. The force of friction**" see Appendix VII.

(pp. 126-127) (cf. Appendix VIII) and they were conducted in the classroom although more emphasis was given in the sliding of block(s) on the surface of a table covered with plastic laminate and sandpaper. Some additional "triggering instances", to those existing in the textbook (p. 126), were used in the first session and some additional every day applications of friction (to those presented in p. 128 of the textbook) were discussed in the second session.

There are quite a few points in the science textbooks which can be criticised and characterised as problematic and misleading for the children (Traianou & Tsagliotis, 1991[4]) Here, there is only a reference in the teaching unit "4. The force of friction" (see Appendix VIII for immediate reference), where some of these points need to be highlighted and commented. They are the following:

- Strangely enough, force is measured in Kp (kiloponts) and not in N (Newtons). The force meters that are depicted in pp. 126-127 and used for measurements are graduated in Kps and not in Newtons. For the present inquiry, this was arranged though, and from the beginning of the unit on "mechanical phenomena" the learners were introduced to the idea of measuring forces in Newtons.

- On p. 126 after the children are invited to take a piece of wood and put it on the table, on one of its sides, they are asked to "pull it with a dynamometer in a way that the body will obtain constant velocity". It is quite difficult for the children to understand what to do since (a) they have not previously been introduced to the concept of velocity[5], (b) they might only have an intuitive idea of what constant velocity is and (c) after all, it is difficult to find a way to move the block of wood at constant velocity, especially by pulling it with your hand (Traianou & Tsagliotis, 1991, p. 17).

- In the teacher's book (1986, p. 66; see Appendix VIII) it is stated that "the nature of the lesson inclines the teacher to place great emphasis on the need for experimental proof for each case referred in this unit". But, the first experiment of the unit, which is with the block of wood sliding on its three different sides in

[4]This is a manuscript which came out of a research project funded by The University of Crete (Code Number 177) which focused on "a contribution to the formation of a proposal for the teaching of physics in primary education aiming to upgrade the respective textbooks from the point of view of physics and pedagogy". The co-ordinator of the research project was Prof. Dr. Demetris Ploumbidis.

[5] In fact, the concept of velocity is not introduced at all throughout the C unit on "mechanical phenomena"!

order to show that "the force of friction is independent of area of the touching surfaces" (p. 126), is quite difficult to conduct successfully, especially when force meters are used to pull the block and measure the force of friction. Furthermore, the concept or property which is supposed to be "revealed" seems to be rather difficult and surprising for the children (cf. Session two, in this section). Thus, during the teaching intervention, this experiment was conducted as a presentation with the guidance of the teacher and it was simultaneously commented and discussed with the learners (cf. § 5.2.4).

This is basically the context in which the teaching intervention was conducted in Greece. The preceding points of critique will be considered again in the final chapter. The classroom setting and the two sessions of the teaching intervention come next.

5.2.2. The classroom setting in Greece

The classroom where the teaching intervention with E' Grade (5th year [6]) took place was a rather small room of 20 m^2 approximately, which was used as the school laboratory (mainly by the 5th and 6th year). There was a small window in the front part of the room and a small door next to the window, on the left (see classroom diagram in fig. 5.2.1). There were two cupboards next to the wall, on the left, which were mainly used for storing science equipment. The chalkboard was at the back of the room, behind the teacher's table.

There were five desks in the room which had the shape of hexagons and were situated in the room as seen in fig. 5.2.1. They were constructed according to UNESCO standards (UNESCO, 1980) and they had recently been installed in the room, roughly at the time that this inquiry was in progress. Each child occupied one side of the hexagon table and they usually left one side free, which faced the centre of the classroom.

[6] For more information on the Greek educational system see the respective diagram in Appendix VIII

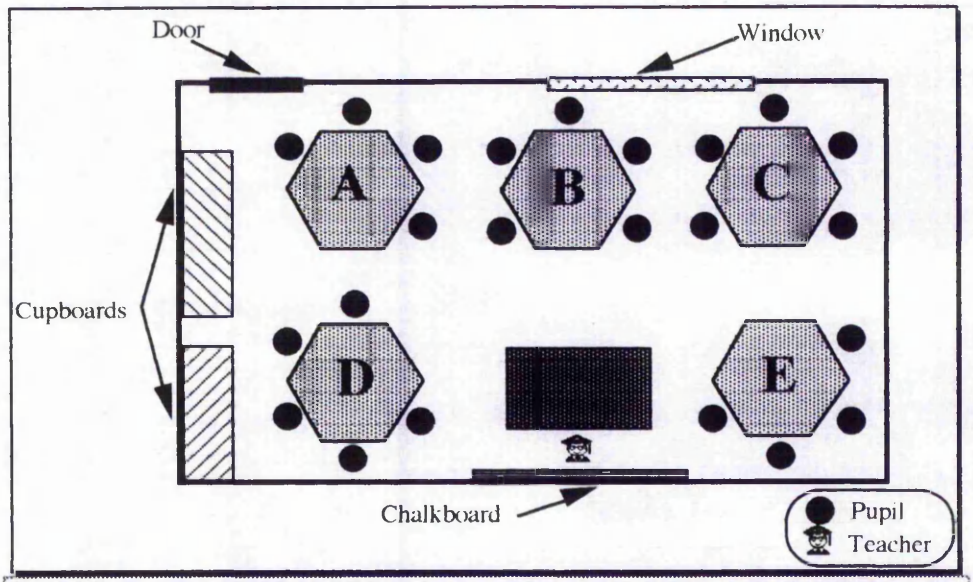


Fig. 5.2.1: The diagram of the classroom, which was also the science laboratory of the school.

In the E' grade there were 23 children (11 boys and 12 girls) and they usually worked in groups. There are letters A-E printed on the desks in fig. 5.2.1 which indicate the respective groups of children. Thus, for example, group A, was situated in the front side of the classroom on the left next to the door.

5.2.3. The first session

This session was a morning session on a Tuesday in the middle of December 1992. It lasted for about one hour and twenty-five (1.25') minutes. Normally this is a continuous morning session, which is used for the teaching of language, but for the purposes of this study it was used for the teaching of science. More precisely an experimental investigation on the concept of friction was organised and conducted. From the beginning of the session the children sat in three groups of five and two groups of four, in the classroom that was used as the science laboratory of the school.

The main foci of the session were to:

- elicit some of the children's ideas or alternative conceptions, concerning frictional phenomena and make them explicit to all involved in the learning process

- provide opportunities for learners to question, investigate and experiment on the nature of frictional force
- encourage learners to acquire new conceptions on frictional phenomena using an explanatory analogy and apply it in various related instances.

These foci would be achieved by means of a series of teaching events and activities encouraging the learners to:

- become aware of their intuitive ideas concerning certain frictional phenomena (e.g. a stationary book on a tilted table) and make them explicit in class by expressing and discussing these ideas, writing them down on a poster and possibly by taking a poll at the end of this process

- test these alternative ideas, in an investigative way, by conducting experiments with blocks of wood, which the children would slide on different surfaces on their tables (e.g. on plastic laminate and on different kinds of sandpaper)

- consider the plausibility of a "scientific explanation" for the nature of friction (static and sliding) which will be presented through the analogy of a jigsaw puzzle and attempt to compare this explanation with prior ideas within the context of new inferences.

- apply the newly acquired ideas to some other similar instances referring to friction, in order to check their plausibility and support their opinions within the context of classroom discussion.

The session started with the teacher presenting an experimental activity which aimed to stimulate children's interest and elicit some of their alternative conceptions. He put a science textbook on one of the edges of the table and then he lifted the table up from that side. The book remained stationary even when the table was lifted higher. The children were asked to explain the phenomenon and most of them said that the book was not "heavy enough" to slide down the table or that gravity was not "strong enough" to pull it downwards. One child from *D* group appeared to consider that this may be true, but she mentioned that "the book also grips on the surface of the table and that is how it gets hold steady in its place". She went further by pointing out that "the cover of the book is catching and gripping on the surface of the table" and that

creates a "holding force" which keeps the book motionless. Some children seemed to agree with this view, while some other children expressed some doubts and said that "gravity is somehow sticking the book on the surface of the tilted table", or that "gravity holds it steady" and that "gravity gets rather weak when the table is lifted higher and then the book starts sliding". The view that the table "is not steep enough" and therefore the book does not slide down, was also expressed. At that moment the teacher said that they should write down these ideas on a poster and then put them to a vote in order to have a better view of what the class thinks about this phenomenon. Each pupil should vote only once. The results of this poll are in table 5.2.1.

Learners' ideas	Results of the poll
• the book is not heavy enough or gravity is not strong enough to pull it down the table	**8**
• there is a "holding force" from the surface of the table that keeps the book stationary	**7**
• the table is not steep enough for the book to start sliding	**3**
• gravity is somehow sticking the book on the surface of the table	**3**
• gravity is not strong enough to pull it down the table, but also the table is not steep enough	**2**

Table 5.2.1: Children's alternative ideas concerning the 'book on the tilted table' situation together with the results of the poll which was held immediately after the elicitation of their ideas.

Thus, most of the children appeared to believe that gravity is not "strong enough" to pull the book down the table. An almost equal number of children suggested that there is "a holding force" which keeps the book in its place. The rest of the children expressed slightly different views (see table 5.2.1). After the poll the teacher said that these were all very interesting ideas and proposed to stick the poster on the wall, in order to discuss it again later.

The teacher moved on with another activity in order to elicit some more of children's alternative conceptions on frictional phenomena. He put a science textbook on his

table and then gave it a gentle push. The book moved forward for a short distance and then it stopped moving. He repeated the same thing for two more times and he asked the children to observe the phenomenon carefully. A volunteer was invited to perform the same activity and this time the book stopped near the edge of the table. The teacher then asked the children to express their ideas on the phenomenon, and more precisely "*why the book slows down and eventually stops moving*". Some of the children expressed the opinion that there was "no more force from the push" that made the book move forward, so the it would slow down and stop as soon as the "force from the push died away". In this respect, some children mentioned that if the book is given a "strong push" then it will travel further, whereas a "weak push", will only make it travel a short distance. Two children from *B* group had a different view and they mentioned that the book "rubs" on the surface of the table and that slows it down. Moreover, they appeared to consider that this "rubbing" depends on the surfaces of the book and the table. Hence, they mentioned that the book they had been experimenting with, so far, had a carton cover and "it rubbed a lot" on the table surface. They suggested that the same book with a plastic cover would slide further because "plastic rubs less with wood", or with "the surface of the table". The rest of the class found this view very interesting and started considering it seriously. At that moment, the teacher found another science textbook decorated with a plastic cover and invited one of the children to test their view experimentally by pushing both of the books, with an equal force, on the surface of the table, in order to test which one would travel further. Before that, he had asked the children to predict the outcome of the experiment and most of them seemed to be convinced that the book with the plastic cover would travel further. Then the child conducted the experiment by pushing both of the books two or three times. The book with the plastic cover moved further all the times. The children tried to explain this by saying that "plastic creates less rubbing" or that "the plastic cover is more slippery than the carton cover of the textbook". The teacher said that these were all very interesting ideas and that they were going to do some similar investigations with the equipment they had on their

tables. He mentioned that the investigations would be with blocks of wood, which they would attempt to slide on the surfaces of the tabletops. In this way, they would investigate the phenomenon further.

Most of the equipment that the children used for these experiments was similar to the one that the children in England had used (cf. § 4.2.5). In Greece, the blocks of wood were a bit heavier (5 N, instead of 4.5 N they weighed in England) although they had the same dimensions, and a reel was used instead of a pulley. A nail was passed through the hole of the reel and then it was fixed on a piece of wood. Then that piece of wood was fixed on the table with a G clamp (see fig. 5.2.2). The weights were also different. They were small cylinders with hooks on both of their ends, so they were hung at the end of the string, instead of using a tray to hold them. Again two of the tables had a strip of "fine" sandpaper, whereas another two had a strip of "rough" sandpaper and only one table was used as it was, with its plastic laminate cover. Force-meters were also available on all of the tables.

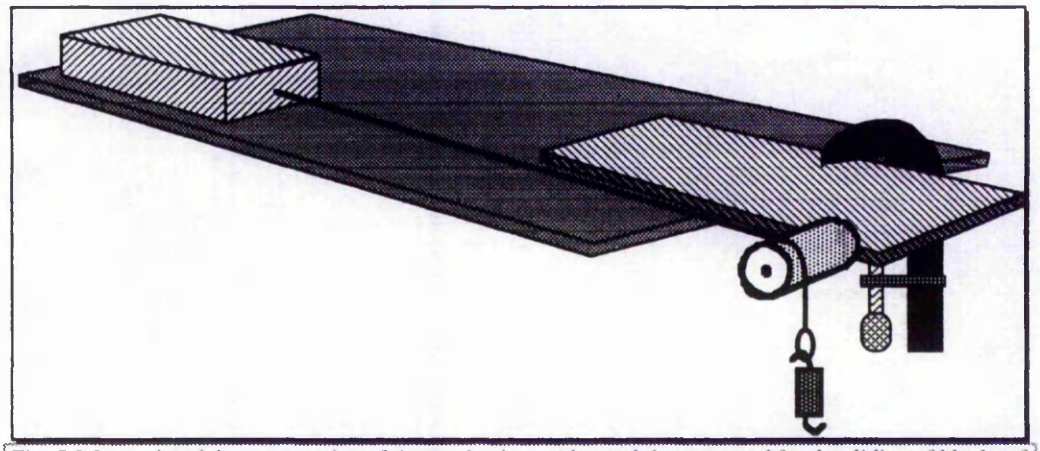


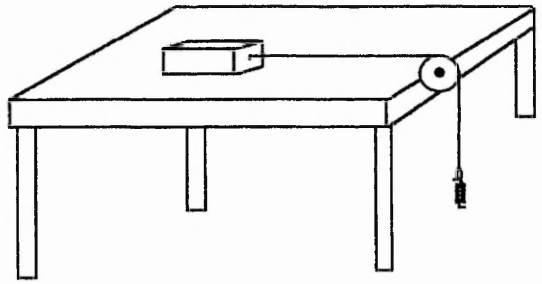
Fig. 5.2.2: A pictorial representation of the mechanism with a reel that was used for the sliding of blocks of wood on the surface of the table, in the investigations conducted by children in Greece.

The children spent some time in getting familiar with the equipment. Then the teacher gave them a leaflet that explained the various activities they were about to do (see fig. 5.2.3). The teacher went though each of the activities, that were presented in the leaflet and answered some explanatory questions, that the children asked. Then he said that in each group there had to be a leader, a scribe, a performer and an

observer or observers, although all of the children should try to perform some experimental activity. He then explained the task that each member of the group had to do and mentioned that after the end of the investigation of each group, the results should be announced in class for further discussion.

Φύλλο Εργασίας

Υπάρχει ένα κομμάτι ξύλο πάνω στο τραπέζι. Είναι συνδεμένο με ένα κομμάτι σπάγγο που περνά γύρω από μια τροχαλία και καταλήγει σε μια θηλειά, όπου μπορούμε να κρεμάμε διάφορα βάρη.



Δραστηριότητες:

1. Ζυγίστε το κομμάτι του ξύλου που βρίσκεται πάνω στο τραπέζι.
2. Κρεμάστε προσεχτικά βάρη στη θηλειά μέχρι το ξύλο να αρχίσει να τσουλάει αργά και σταθερά.
3. Σημειώστε πόσο βάρος θα έπρεπε να χρησιμοποιήσετε για να αρχίσει το ξύλο να τσουλάει αργά και σταθερά
4. Συγκρίνετε το βάρος του ξύλου με το βάρος που χρησιμοποιήσατε για να αρχίσει τ ξύλο να τσουλά αργά και σταθερά. Τι παρατηρείτε;
5. Προσθέστε άλλο ένα κομμάτι ξύλο πάνω σ' αυτό που έχετε ήδη στο τραπέζι. Επαναλάβετε τις δραστηριότητες **2** & **3**.
6. Συγκρίνετε το βάρος που έπρεπε να χρησιμοποιείσετε για να τσουλήσουν τα κομμάτια από ξύλο πάνω στο τραπέζι, με το βάρος των ξύλων. Τι παρατηρείτε;

Ομαδική εργασία:

Κάθε ομάδα να εργαστεί συλογικά. Στο τέλος της εργασίας, ένας εκπρόσωπος της ομάδας να ανακοινώσει τα αποτελέσματα από τις δραστηριότητες της ομάδας.

Προσοχή:

Να κρεμάτε τα βάρη προσεχτικά το ένα κάτω από το άλλο. Μην κουνάτε το τραπέζι όταν προσπαθείτε να εκπληρώσετε τις παραπάνω δραστηριότητες.

Fig. 5.2.3: The leaflet that was distributed to the children during the first session of the teaching interventions in Greece.

The investigation started with the teacher asking one child in each group to weigh a block of wood. They all came up with the same measurement, that the block of wood weighed 5 Newtons. He then asked the children to predict how much force would be needed for the block of wood to start sliding on the surface of the table. Two children from *B* group claimed that a "pulling force" equal with the weight of the block would

be needed for it to start sliding along the surface of the table, "otherwise it would grip and it wouldn't slide". Most of the children appeared to agree with that view, apart from one child from *E* group who mentioned that if an equal force was needed for the block to start sliding "it would be the same as if we lifted it". He mentioned that as he had observed, at his father's warehouse, that it is always easier to move a big, heavy box by sliding it on the floor instead of lifting it up and then move it. So he claimed that less force from the weight of the block will be needed for its sliding because "the table is also lifting some of its weight". The rest of the children found this idea a very interesting one although some had their reservations. At that moment they couldn't wait to see who was right and who was wrong. The teacher told them to start their investigation, but also advised them to add the weights gradually and carefully, in order to have a fair test and to keep a better record of measurements. Likewise the study in England, the same format for recording of data was used (cf. § 4.2.5.). While the children were conducting the investigations the researcher was moving around the tables, acting as a teacher-assistant, helping the children to organise their activities and record their data.

The teacher asked group *B* to experiment with one block of wood on the tabletop covered with plastic laminate. They started adding weights gradually and the scribe was keeping the record. They were surprised when they found out that the block of wood started sliding with a "pulling force of 1.3 Newtons" (see Table 5.2.2). They expected that a greater force would be needed to "break the grip of the block of wood and the table and start it sliding". One of the children of this group observed that the block does not slide very fast on the tabletop and she explained that it happens "because the block is rubbing on the tabletop when it slides and this slows it down". She went further to make a more general statement by saying that "things that move slow down when they rub, like the book on the table". The rest of the group seemed to agree with that observation.

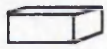
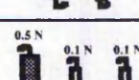
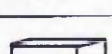
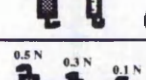
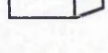
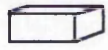
Weight of the block(s)	Weights hung at the end of the string	Effect on the block(s)	
		No sliding	Sliding
 5 N	 0.2 N	✓	
 5 N	 0.3 N	✓	
 5 N	 0.4 N	✓	
 5 N	 0.5 N	✓	
 5 N	 0.6 N	✓	
 5 N	 0.7 N	✓	
 5 N	 0.8 N	✓	
 5 N	 0.9 N	✓	
 5 N	 1 N	✓	
 5 N	 1.1 N	✓	
 5 N	 1.2 N	✓	
 5 N	 1.3 N		✓

Table 5.2.2: ***Group B.*** A representation of the record they kept when they experimented with one block of wood on a tabletop covered with plastic laminate.

Then the same group went on to experiment with two blocks of wood. They found out that a "pulling force" of 2.5 Newtons was needed for the blocks to start sliding. The scribe wrote down that this was "exactly $^1/_4$ of the weight of the blocks" and he mentioned that this is also "nearly correct for one block of wood" (see Table 5.2.3). The leader of the group mentioned that when they use two blocks of wood, one on top of the other, they need "a double pulling force" from the weights to start them sliding on the tabletop.

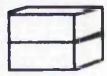
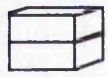
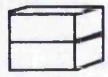
Weight of the block(s)	Weights hung at the end of the string	Effect on the block(s)	
		No sliding	Sliding
 10 N	 1.3 N	✓	
 10 N	 1.4 N	✓	
 10 N	 1.5 N	✓	
 10 N	 1.8 N	✓	
 10 N	 2 N	✓	
 10 N	 2.1 N	✓	
 10 N	 2.3 N	✓	
 10 N	 2.4 N	✓	
 10 N	 2.5 N		✓

Table 5.2.3: Group B. A representation of the record they kept when they experimented with two blocks of wood on a tabletop covered with plastic laminate.

Groups *A* and *C* first experiment with one block of wood which they tried to slide on a strip of "fine" sandpaper, which was stuck on their tables. Both of the groups found out that they needed a "pulling force of 2.5 Newtons" to start the sliding of the block (see Table 5.2.4). The leader of group *C* mentioned that this was exactly half of the weight of the block. The children in group *A* mentioned that they expected the "pulling force" to be greater because "the block would grip more on the sandpaper than on the plastic laminate".

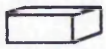
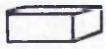
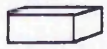
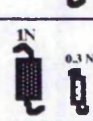
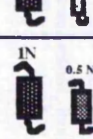
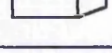
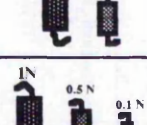
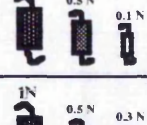
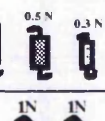
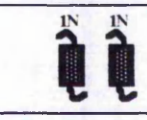
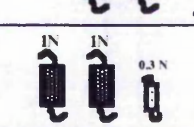
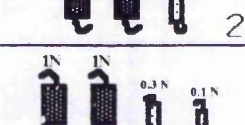
Weight of the block(s)	Weights hung at the end of the string	Effect on the block(s)	
		No sliding	Sliding
 5 N	 0.3 N	✓	
 5 N	 0.5 N	✓	
 5 N	 0.6 N	✓	
 5 N	 0.8 N	✓	
 5 N	 1 N	✓	
 5 N	 1.3 N	✓	
5 N	 1.5 N	✓	
 5 N	 1.6 N	✓	
 5 N	 1.8 N	✓	
 5 N	 2 N	✓	
 5 N	 2.3 N	✓	
5 N	 2.4 N	✓	
 5 N	 2.5 N		✓

Table 5.2.4: ***Groups A & C.*** A representation of the record they kept when they experimented with one block of wood on a tabletop covered with "fine" sandpaper.

Then the teacher asked group *A* to experiment with two blocks of wood. They found out that a force of 5 Newtons was needed for the set of two blocks of wood to start sliding on the tabletop covered with "fine" sandpaper (see Table 5.2.5).

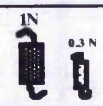
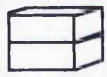
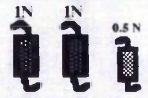
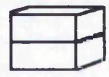
Weight of the block(s)	Weights hung at the end of the string	Effect on the block(s)	
		No sliding	Sliding
 10 N	 1.3 N	✓	
 10 N	 1.8 N	✓	
 10 N	 2 N	✓	
 10 N	 2.5 N	✓	
 10 N	 2.8 N	✓	
 10 N	 3 N	✓	
 10 N	 3.5 N	✓	
 10 N	 4 N	✓	
 10 N	 4.5 N	✓	
 10 N	 4.8 N	✓	
 10 N	 5 N		✓

Table 5.2.5: ***Group A.*** A representation of the record they kept when they experimented with two blocks of wood on a tabletop covered with "fine" sandpaper.

Group *C* used three blocks of wood to experiment on the surface of "fine" sandpaper and found out that a force of 7.5 Newtons was needed for the blocks to start sliding

on the tabletop (see Table 5.2.6). Again this was "half of the weight of the blocks", as the scribe mentioned.

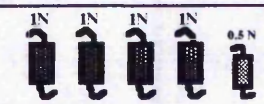
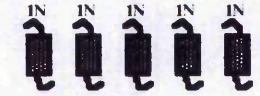
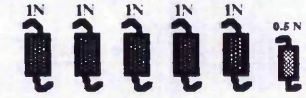
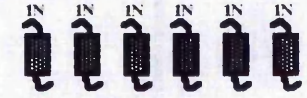
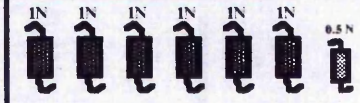
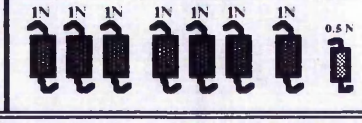
Weight of the block(s)	Weights hung at the end of the string	Effect on the block(s)	
		No sliding	Sliding
 15 N	 4.5 N	✓	
 15 N	 4.8 N	✓	
 15 N	 5 N	✓	
 15 N	 5.5 N	✓	
 15 N	 6 N	✓	
 15 N	 6.5 N	✓	
 15 N	 7 N	✓	
 15 N	 7.3 N	✓	
 15 N	 7.5 N		✓

Table 5.2.6: ***Group C.*** A representation of the record they kept when they experimented with three blocks of wood on a tabletop covered with "fine" sandpaper.

Groups *D* & *E* experimented on a strip of "rough" sandpaper. First the teacher asked both of the groups to experiment with one block of wood. They did so and they found out that the block would start sliding with a "pulling force" of 2.8 Newtons (see Table 5.2.7). This was calculated to be nearly $^{3}/_{5}$ of the weight of the block. The children mentioned that they expected it to be a lot more, because the sandpaper was

"very rough" and the block would "grip" or "catch" on it with "a lot of power", hindering the movement of the block.

Weight of the block(s)	Weights hung at the end of the string	Effect on the block(s)	
		No sliding	Sliding
5 N	0.3 N	✓	
5 N	0.5 N	✓	
5 N	0.5 N + 0.3 N = 0.8 N	✓	
5 N	1 N	✓	
5 N	1 N + 0.5 N = 1.5 N	✓	
5 N	1 N + 0.5 N + 0.3 N = 1.8 N	✓	
5 N	1 N + 1 N = 2 N	✓	
5 N	1 N + 1 N + 0.3 N = 2.3 N	✓	
5 N	1 N + 1 N + 0.3 N + 0.1 N = 2.4 N	✓	
5 N	1 N + 1 N + 0.3 N + 0.3 N = 2.6 N	✓	
5 N	1 N + 1 N + 0.3 N + 0.3 N + 0.1 N = 2.7 N	✓	
5 N	1 N + 1 N + 0.3 N + 0.3 N + 0.1 N + 0.1 N = 2.8 N		✓

Table 5.2.7: ***Groups D & E.*** A representation of the record they kept when they experimented with one block of wood on a tabletop covered with "rough" sandpaper.

Group *D* experimented with two blocks of wood on "rough" sandpaper and they found out that the blocks would start sliding when a "pulling force" of 5.8 Newtons

was exerted on them (see Table 5.2.8). This force appeared to be nearly $^{3}/_{5}$ of the weight of the blocks.

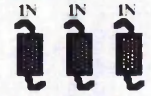
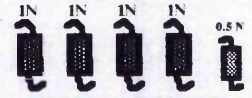
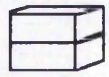
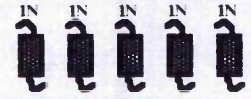
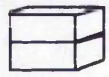
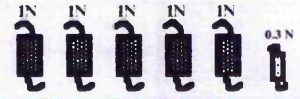
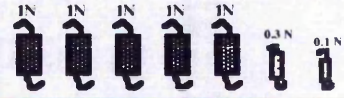
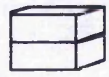
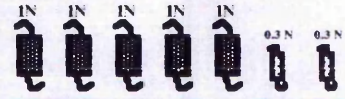
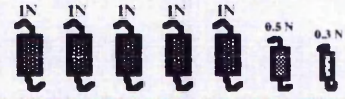
Weight of the block(s)	Weights hung at the end of the string	Effect on the block(s)	
		No Sliding	Sliding
 10 N	 1.8 N	✓	
 10 N	 2.5 N	✓	
 10 N	 3 N	✓	
 10 N	 3.5 N	✓	
 10 N	 4 N	✓	
 10 N	 4.5 N	✓	
 10 N	 4.8 N	✓	
 10 N	 5 N	✓	
 10 N	 5.3 N	✓	
 10 N	 5.4 N	✓	
 10 N	 5.6 N	✓	
 10 N	 5.8 N		✓

Table 5.2.8: ***Group D.*** A representation of the record they kept when they experimented with two blocks of wood on a tabletop covered with "rough" sandpaper.

Group *E* experimented with three blocks of wood on the same surface of "rough" sandpaper and they found out that a "pulling force of 8.8 Newtons was needed for the set of blocks to start sliding (see Table 5.2.9). Again this was calculated to be approximately $^{3}/_{5}$ of the total weight of the blocks.

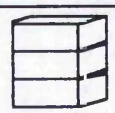
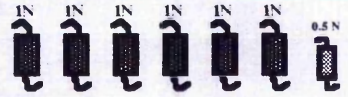
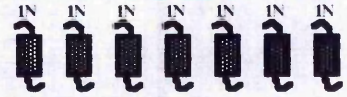
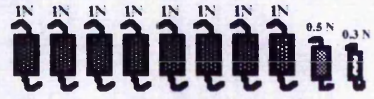
Weight of the block(s)	Weights hung at the end of the string	Effect on the block(s)	
		No sliding	Sliding
 15 N	 4.5 N	✓	
 15 N	 5 N	✓	
 15 N	 5.5 N	✓	
 15 N	 6 N	✓	
 15 N	 6.5 N	✓	
 15 N	 7 N	✓	
 15 N	 7.5 N	✓	
 15 N	 8 N	✓	
 15 N	 8.5 N	✓	
 15 N	 8.8N		✓

Table 5.2.9: ***Group E.*** A representation of the record they kept when they experimented with three blocks of wood on a tabletop covered with "rough" sandpaper.

This investigation took roughly half an hour. After all of the children had finished their activities, the teacher invited the leader of each group to announce their thoughts and conclusions to the rest of the class.

Group *B* mentioned that they now support the opinion that the table is lifting most of the weight of the block, therefore a force of only $^1/_4$ of its weight can slide it on the table. But, they also claimed that there is some kind or "resistance" pulling the block in the opposite direction of the intended movement, which doesn't allow it to be moved with a smaller force. They suggest that this force has to do with the nature of the surfaces in contact which can "grip more or less with each other".

Both groups *A* & *C* mentioned that they expected the block(s) to slide with a greater force, since they thought that there would be "more grip with the surface of the sandpaper". But, they also appeared to be sensing that the table "holds some of the weight of the block when it is pulled" and in this way "it somehow helps the pulling force, which doesn't have to be that much". Group *C* mentioned that they had observed that when the block(s) slid on the table, it left a visible trace on the sandpaper. They explained it by suggesting that these "little pieces of wood snap off from the surface of the block when it rubs on the sandpaper". After all, they indicated that "sandpaper is used for purposes like that". Group *A* mentioned that gravity is pulling the block(s) down onto the table and that helps the "grip", which doesn't let the block(s) to move with a smaller force. They indicate that "gravity somehow helps the block to stick on the surface of the table". Group *C* agreed on that last point of group *A*.

Groups *D* & *E* mentioned that they expected the need of a "great pulling force" in order to pull the block(s) on the tabletop covered with "rough" sandpaper. But they also claimed that the table "supports the block, in a way" and in this respect the "pulling force of the weights does not have to lift all of the weight of the block". Group *D* suggested that the grip which "holds back" the block when the "pulling force is not yet enough" has to do with the "kind of surfaces that are touching each other".

Thus, rather intuitively, they indicated that "rough surfaces would create more grip than smooth surfaces". Group *E* appeared to be sharing this idea, but they also mentioned that "the weight of the block helps it to grip on the table, because it is pressing it on its surface".

The teacher mentioned that these were all very interesting ideas, but he put forward another question: "*How does the block of wood grip on the surface of the table whether it is plastic laminate or sandpaper?*". The children replied that "gravity" or "the weight of the block" "press" or "stick" the block on the surface of the table. One child suggested that "it is as if the two surfaces are holding and catching with each other". At that moment the teacher presented the analogy with the jigsaw puzzle (cf. § 4.2.5). He stuck the two fragments of a jigsaw puzzle on the board and explained that the two surfaces of the block of wood and the table "get into one another" in a similar way. It is as if they "interlock" and in this way they "grip" or they "create friction". He mentioned that "friction" is the word that scientists use to refer to phenomena dealing with surfaces in contact that grip with each other. The children seemed to find the analogy with the jigsaw puzzle a fruitful way to explain the phenomenon under consideration.

One of the children from *D* group pointed out that she thought that friction had to do only with "rubbing", but now with the jigsaw puzzle she understands that "there can still be friction when two surfaces do not rub with each other". Another child pointed at the poster that was on the wall and said that "the same thing happens with the textbook on the tilted table, or with the block of wood before it starts sliding". At the same time though, she wondered what happens with the surfaces or with "the two pieces of the jigsaw puzzle when one of them starts moving". The teacher took the upper fragment of the jigsaw puzzle and moved it on top of the lower. He then asked the children what they observed. They replied that the upper fragment of the puzzle moved up and down on the "little projections and crannies" of the lower fragment of the puzzle. The teacher pointed out that a similar thing happens with the two surfaces

of the block and the table when they are in contact and one slides over the other. The "roughness" of the surfaces or "the little hills and valleys" that they have, get into one another and "sometimes some bits of the surfaces snap off". One child suggested that the same thing happens with the "small bits of wood" that they could see on the sandpaper when the block was sliding on top of it. The teacher asked that child if he thought that there was still friction when the block slid on the tabletop. The child replied affirmatively and explained that the surfaces would still "get into one another, but they can't hold with each other because "the pulling force from the weights is greater". Another child added that if there was no friction "the block would slide along the table a lot faster, so friction slows it down a bit". A third child suggested that it is as if "the roughness of one surface is hitting the roughness of the other and that can create friction".

At that moment, the teacher asked the children what direction they thought that the "arrow" of the force of friction had. Most of the children suggested that it should have a direction opposite to the motion, or the intended movement of the block, because it is "as if friction is holding the block back and doesn't let it go". Some other children expressed the opinion that there should also be some "little forces of friction", at the points of contact where the "projections and cavities" of the block of wood and the table "get into one another". They suggested that the force of friction can be "all of these bits of friction together".

Nearly at the end of the session, the teacher asked the children to summarise some of the points that came out of their investigations or were discussed in class. The children came up with a list that the teacher wrote on another poster:

- there is more friction when the weight of the block(s) becomes more (we add more blocks) because a greater pulling force is needed to slide the block(s) on the table;
- the surfaces get into one another because they are rough and they interlock like two pieces of a jigsaw puzzle with their small "projections and cavities";

- when the block is sliding there is still some friction because the "little hills and valleys" of its surfaces are "hitting" the "roughness" of the surface of the tabletop;
- the arrow of the force of friction is in the opposite direction the motion of the block.

That's roughly where the first session ended. The teacher mentioned that in the following session they would do some more experiments on the concept of friction with the blocks of wood.

5.2.4. The second session

This session was conducted in the following day, again during the morning session and it lasted for approximately one hour and twenty-five minutes (1.25').

The main intentions of the session were to:

- to help the children clarify some ambiguous aspects of friction, by negotiating them in class.
- to investigate with an experiment and discuss the notion that friction (for rough surfaces) is independent of the area of contact of two surfaces.
- to present and discuss some practical aspects of friction from our daily life.
- to assess children's understanding on the nature of frictional force, by asking them to present a relevant drawing and express their ideas in a written form.

The session started with the teacher reminding the children about the investigations on friction they had conducted the previous day, with the blocks of wood they slid on their tables. He also asked two of the children to read the posters that the class had written. After that he took a block of wood and put it on his table. He asked the children on how many different sides the block could stand. They replied that there are three possible sides that a block can stand on the table. The teacher then reminded them that in the experiments they had conducted on the previous day they had used the blocks of wood with their largest side touching the tabletops. He went further to

ask them how much pulling force would be needed for the block to start sliding if it stood on one of its other sides. Most of the children replied that "the smallest the area of contact" would be, "the less friction the block would create with the tabletop". Hence, they expected that a smaller force would be needed for the block to start sliding, if it stood on the its two "smaller sides". Some children expressed some doubts but they claimed that they didn't know what was going to happen.

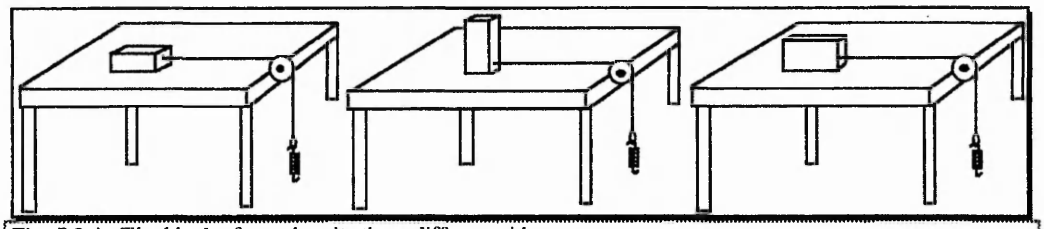


Fig. 5.2.4: The block of wood on its three different sides.

The teacher placed the block of wood on his table and stood it vertically on its smallest side (see fig. 5.2.4., the drawing in the middle). He then asked two children to hang some weights at the end of the string and to keep a record of their measurements on the board. The children seemed to be very surprised when the block of wood started sliding with a "pulling force of 1.3 Newtons", which was the same force it needed when it was placed on its largest side (see fig. 5.2.4., the drawing in the middle). The children looked a bit puzzled for a moment and they couldn't explain the phenomenon. Then one child suggested that "the block hasn't changed, it is still the same block". Another child indicated that "the weight of the block hasn't changed either" and she pointed out that "it's just the same weight of the block which is spread on a smaller area, therefore nothing has changed". The rest of the children found it to be an interesting idea and they expressed their curiosity on whether the same pulling force would be needed for the block to start sliding when it is placed on its other side. The teacher invited two other children to conduct the experiment, at his table and the rest of the class watched carefully (see fig. 5.2.4., the drawing on the right). They found out that the same pulling force of 1.3 Newtons was needed to slide the block of wood on the tabletop, covered with plastic laminate.

They seemed to be happy that their explanation proved to be correct, also for this case. The teacher asked them to form a conclusion referring to the experiment they had just conducted in order to add it on their poster. The children came up with the following:

- friction is independent of the area of contact of a certain object (block) with a surface (tabletop), because the same weight of the object is spread over the areas of it different sides; therefore there isn't any change.

After that, the teacher posed a different question: "*How could you make the block slide easier on the tabletop, that is, with less pulling force?*". The children came up with two ideas. One was to use some kind of rollers, like pens or pencils, and the other was to put some oil or grease on the surface of the tabletop to "ease the way of the block". The teacher invited the children to put their ideas into practice with the block of wood that was on his table.

Hence, one child put three pens under the block of wood and started to hang some weights carefully, at the end of the string. The block started sliding with a pulling force of approximately 0.6 Newtons, nearly half of the force that block needed to start sliding. The child suggested that it happened as she had expected and she also claimed that "it is easier to move something on rollers or wheels instead of sliding it". The rest of the class appeared to agree with the idea, and the teacher asked the child to add it on their poster. Then he asked the class if they thought that there was any friction at the points that the rollers (pens) are touching the tabletop, when the block of wood is rolling. One child replied that there would still be some friction, because "the block of wood needs some pulling force to start it sliding and there is still some area of contact between the pens and the tabletop". Another child added that "friction would be a lot less if they used wheels, which are perfectly round and the area of contact is even smaller". The rest of the class seemed to share these beliefs.

Then the teacher invited another child to put some oil on the tabletop and under the block of wood and then try to slide it. The child found out that a pulling force of 0.8 Newtons was needed for the block to start sliding. Thus he clamed that "oil helps the block to start sliding and make less friction with the surface of the tabletop". Another child indicated that there would be even less friction if they used grease because "grease is more slippery than oil". There was no grease available in the classroom so the teacher said that they could test it some other time. Nevertheless, he asked the children how they thought that friction "becomes less" when there is oil in between the surfaces in contact. One child suggested that the "projections and the cavities of the surfaces get oily and they become very slippery". Another child mentioned that when grease is used, "it is difficult for the surfaces to come to contact" and claimed that "a similar thing could happen with oil". The class found these ideas very interesting and they decided to write them down on their poster.

After that, the teacher asked them to mention some cases where they have seen such ways of minimising friction to be used. One of the children referred to a case where a boat was pushed into the water by using big logs to move it across the beach. Another child mentioned that he uses oil to "have less friction" in many cases like "on the doors, in order not to get stiff", or the "various parts of a machine, or a bicycle", in order to "work in a smooth way".

Then they were asked if they knew any cases where "we need to have a lot of friction". One of the children suggested that the cars need to have good tyres "to grip on the road and create friction", when they run very fast. Another child mentioned that the same should happen with our shoes. If they are made out of rubber, like trainers, they grip on the road and "create a lot of friction", where as if the "sole of the shoes is made out of leather, which is not very rough, we may slip and fall a lot easier".

For the last fifteen minutes or so, the children were given a translation of the "drawing and writing" test, that the children in England had filled in (cf. § 4.2.6. and

Appendix VIII). Some of the children's responses are presented and commented below.

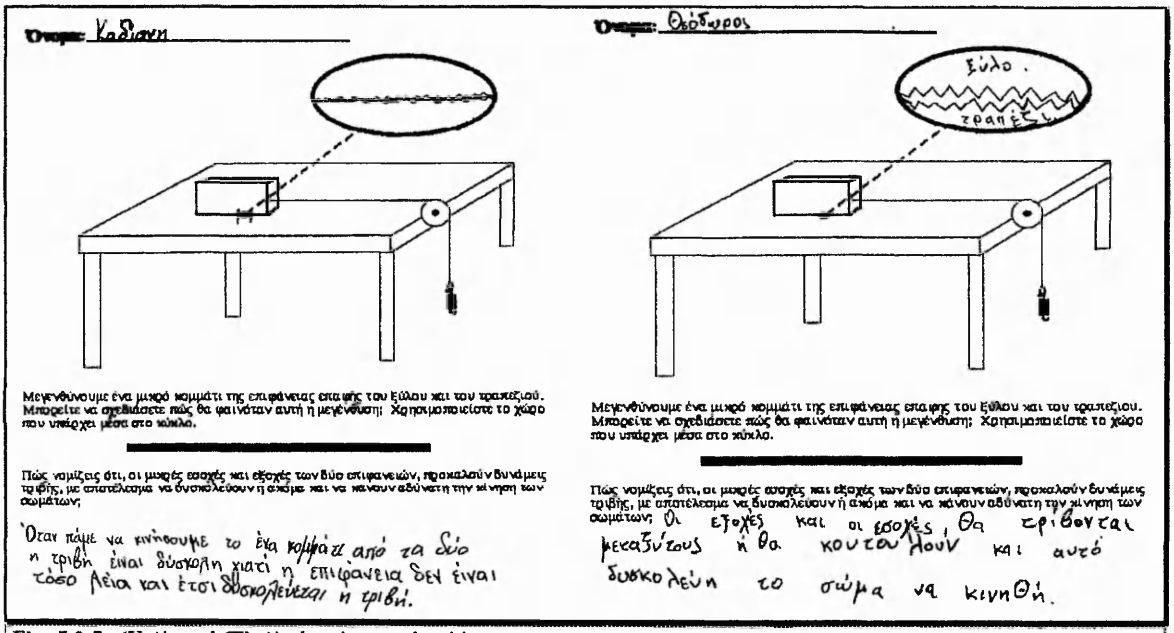


Fig. 5.2.5: (**Ka**)'s and (**The**)'s drawings and writing.

(**Ka**) and (**The**) made very nice drawings representing the two surfaces of the block of wood and the table that come to contact and get into one another (see fig. 5.2.5). (**The**) has even written what each part of his drawing represents. (**Ka**) has written that "when we attempt to slide a piece of wood, friction is difficult because the surface is not so smooth and so friction gets more difficult". She appears to be considering friction as "something" or an "entity", which "gets more difficult" because the surface "is not so smooth". Thus, although she seems to hold a conception that rough surfaces create friction, she doesn't seem to have a clear conception on how friction is created. On the contrary (**The**) claims that "the projections and the cavities will be rubbing with each other or will be hitting each other and this will make it difficult for the block to move". He appears to be holding a very clear conception about the interlocking of surfaces and how that creates friction.

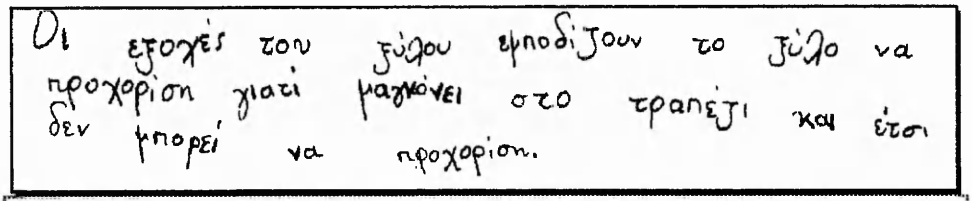


Fig. 5.2.6: (**He**)'s writing

(**He**) suggests that "the projections of the block of wood are hindering its movement because it gets stuck on the table and so it can't move" (see fig. 5.2.6). (**He**) appears to be considering that the irregularities of the block interlock or "get stuck" on the surface of the tabletop and this creates friction, which "hinders the movement of the block".

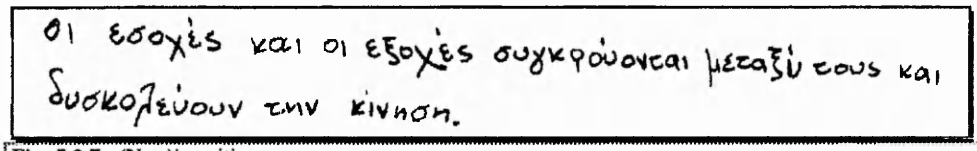


Fig. 5.2.7: (**Nou**)'s writing.

Likewise, (**Nou**) points out that "the projections and the cavities are hitting with each other and they make the movement difficult" (see fig. 5.2.7).

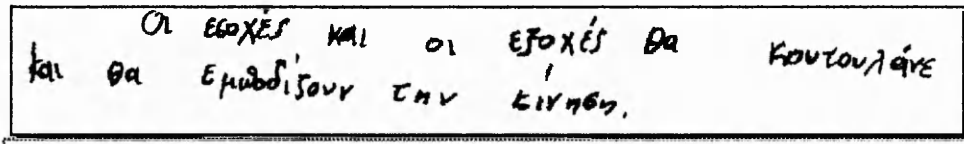


Fig. 5.2.8: (**Ya**)'s writing.

In a similar way, (**Ya**) indicates that "the projections and cavities will be hitting each other hindering the motion" (see fig. 5.2.8).

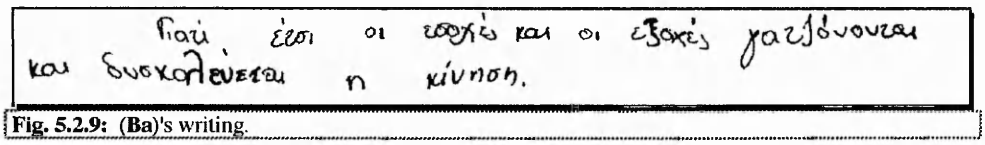


Fig. 5.2.9: (**Ba**)'s writing.

(**Ba**) suggests that "because the projections and the cavities are grasping with each other the movement becomes difficult" (see fig. 5.2.9). She is using the expression "grasping with each other" perhaps to indicate a notion of the interlocking of surfaces.

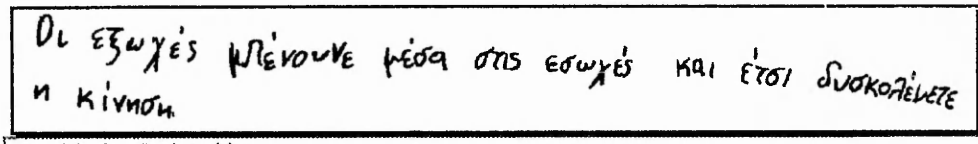


Fig. 5.2.10: (**Ge**)'s writing.

(**Ge**) appears to be describing the interlocking of surfaces in a better way when he points out that "the projections are getting inside the cavities and this is how the motion is hindered" (see fig. 5.2.10).

5.3.0. The "draw the arrow of friction" test (Greece)

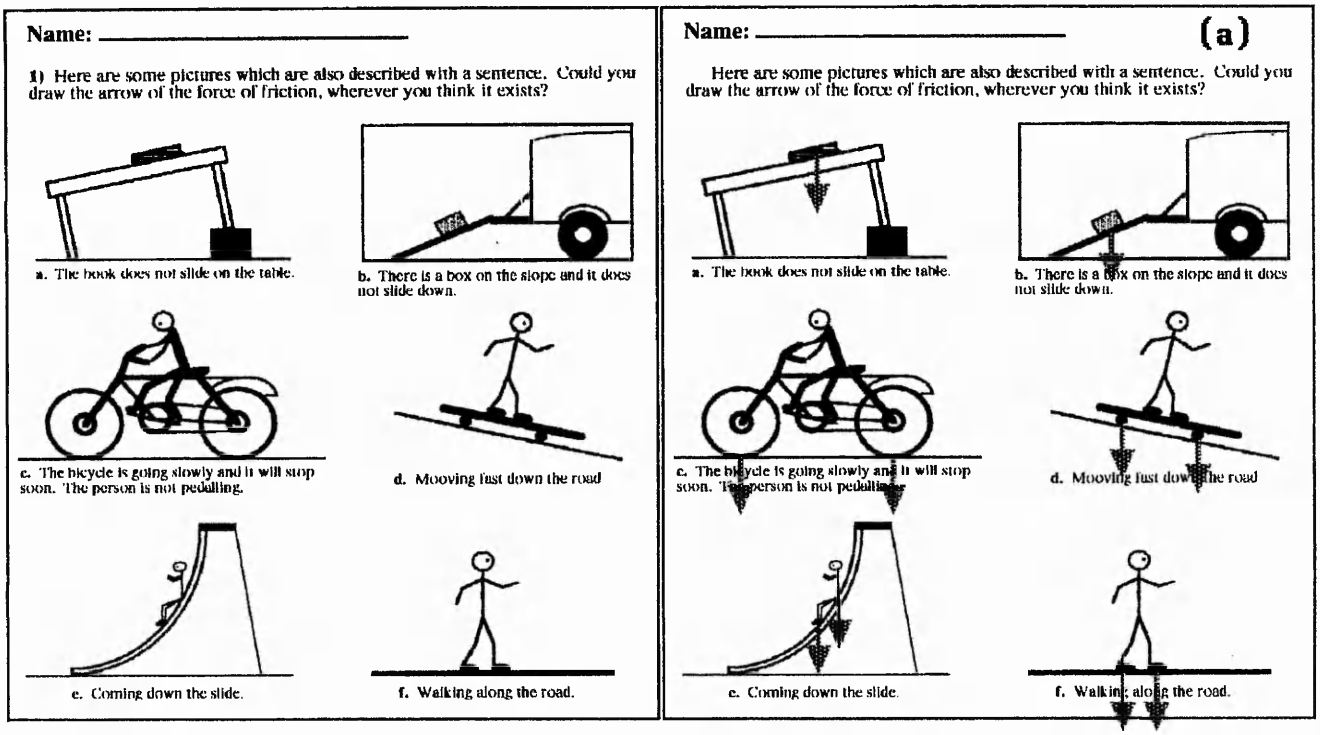
This was a kind of picture test, which presented six instances where friction (static, sliding or rolling) was present (see fig. 5.3.1 and Appendix VIII). The test was given to the children a week after the teaching intervention and it mainly aimed to collect information about children's ideas in reference to the direction that the "arrow" of friction has, in the depicted instances, which were the same or similar to the interview instances. Thus, the children were asked to draw "the arrow of friction" wherever they thought that it existed, but as they commented in the beginning of the activity, "there can be instances that two arrows of friction can be drawn". Their responses are represented here in three groups.

Hence, the children of the first group (9 out of 23) appear to believe that the force of friction is pointing downwards, in a vertical direction and in this way, it somehow "sticks" the surfaces together, makes things "hold" on surfaces, or it "slows things down" (see (**a**) in fig. 5.3.1). Thus, for example in the '*person walking along the street*' instance they represent friction with two arrows pointing downwards, one for each of the shoes of the person respectively. They probably consider friction in this way, because it looks as if it is "keeping the person on the road" (cf. Post-Intervention Interview analysis, § 5.4.b.)

The children of the second group (5 out of 23) symbolise friction with an arrow pointing in the opposite direction of the motion, or the intended movement of bodies (see (**b**) in fig. 5.3.1). Thus, for example, in '*the skateboard moving down the road*' instance, they symbolised friction with two arrows, one for each wheel respectively, pointing upwards to the left, along the surface of the road and in the opposite direction of the motion of the skateboard. This is possibly implying that they consider friction as a force that is hindering the motion of the skateboard, or the bike slowing them down (cf. Post-Intervention Interview analysis, § 5.4.e.).

The children of the third group (7 out of 23), appear to be using two arrows to symbolise friction in each case (see (**c**) in fig. 5.3.1). Thus, in the '*book on the tilted table*' instance, for example, they use one arrow pointing downwards, at the interface of the book and the table, and another arrow pointing upwards, again at the area of contact of the book and the table. They appear to have in mind the interlocking of surfaces, which are "getting into one another", creating friction. Hence, they probably represent the "interlocking" of surfaces, in this case. Perhaps they are also influenced by the analogy of the jigsaw puzzle which may have created this alternative and unexpected conception (cf. Post-Intervention Interview analysis, § 5.4.a.).

Only two (2) children appear to be using a combination of all three cases described above to represent friction. Their answers are miscellaneous and they can not be put to any of the three groups.



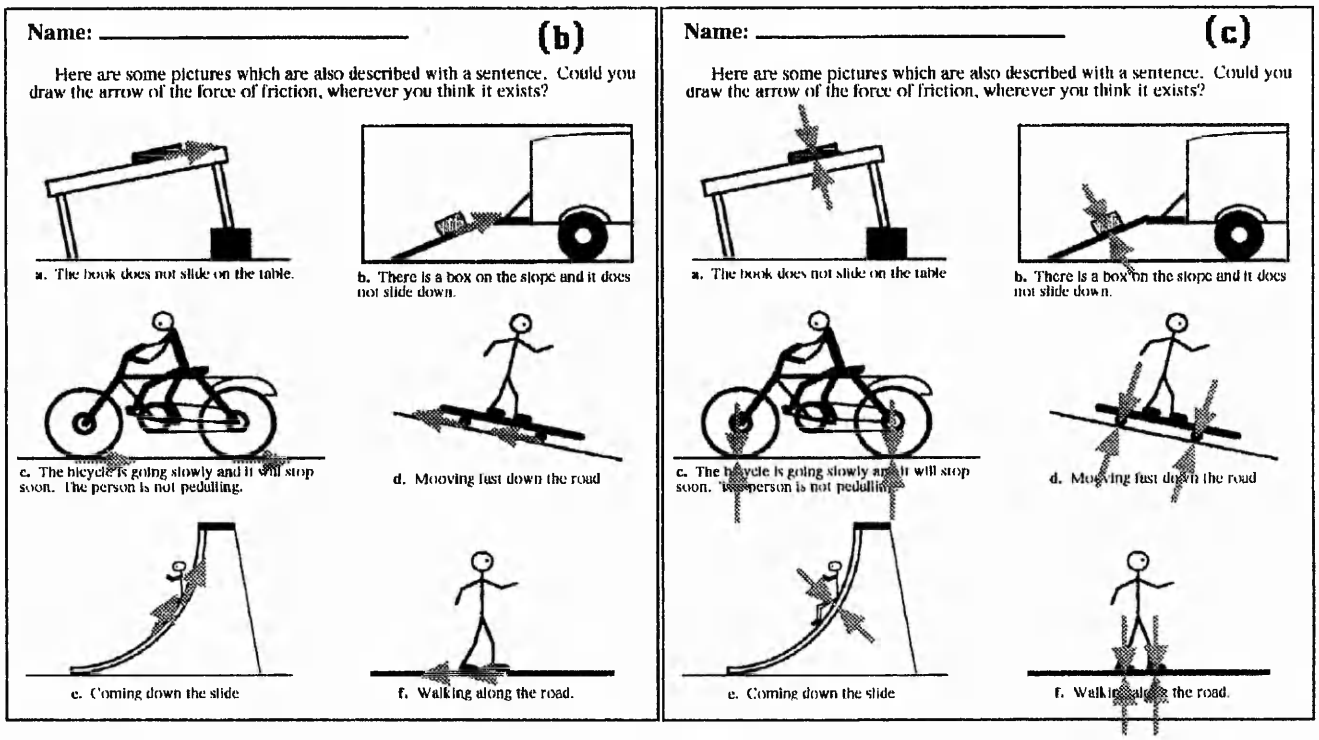


Fig. 5.3.1: The three groups of children's responses in the "draw the arrow of friction" test (Greece).

5.4.0. Post-Intervention Interview Analysis (Greece)

Likewise the study in England, the purpose of the analysis of the post-intervention interviews is to identify, present, and interpret groupings of conceptions and alternative conceptions, about friction and/or frictional phenomena, held by the children who participated in this study, after the teaching intervention. In most of the cases, the children in Greece where asked to represent the force of friction with an arrow referring to how they thought it was exerted in the depicted instances and their responses are presented at the end of the analysis of each card respectively. The section is concluded with a discussion.

5.4.a. The card with 'the book on the tilted table' instance

*Four children (**Ge, Ba, Ni, Joh**) appear to be considering friction between the surface of the book and the surface of the table in terms of "rough" surfaces that interlock or get into one another.*

(**Ni**) for example appears to be considering that since the table is not "smooth" or "flat", it holds the book there because it "grips" with the surface of the book which is also "rough" (006 & 008). Thus, "friction is exerted", due to "little hills and valleys" that the surfaces have, which "catch on each other" (008).

006	**Ni**	er .4.. yes .. friction is holding it there .. because the table is not smooth .. flat .. er .. it has some asperities .. and it can hold the book ..
007	**Int**	how do you think that it holds the book .. / .. as you say ..
008	**Ni**	er .. the book ... its cover .. it is not smooth also.. it has a rough surface .. and with the rough surface of the table .. somehow they grip together and so friction is exerted .. er.. the surfaces have little hills and .. valleys .. and so they catch on each other ..

In a similar way (**Joh**) appears to be suggesting that because the table and the book are "rough", they will "hold" on each other (008). He points out the analogy of the jigsaw puzzle and says that the same thing happens with the "irregularities" of the table that "get into the little valleys of the book" (010). He mentions though, that if the table was made of "ice", the book would slide "very easily" (011).

008	**Joh**	er .. because the table is rough .. but also the book .. er .. so it will hold .. er .. the book will hold on the table ..
009	**Int**	can you describe .. how do you think that it happens .. /
010	**Joh**	er .. it looks like the jigsaw puzzle .. er.. but because the book is not totally smooth .. it is as if it has some little hills and valleys .. the same happens with the table .. so the irregularities of the table get into the little valleys of the book and the opposite .. so the table will hold the book ..
010.5	**Int**	>> umm hmm ..
011	**Joh**	.. but if the table was made of .. ice .. the book would slide very easily .. but now that it is wooden .. it can hold the book ..

*Three children (**Geo, Bi, Nt**) appear to be considering that the weight of the book somehow "helps" friction to hold it stationary up on the surface of the table. Moreover, (**Nt**) emphasises on the role of weight in holding the book motionless and considers "friction as a helping force".*

Thus, (**Geo**) points out that the "weight of the book", "together with friction" keep the book stationary on the table (008). She appears to be considering that friction is created due to the roughness of the surfaces of the book and the table. Hence, the rough surfaces "interlock" with each other (008), or "fix a bit", creating friction (010).

008	**Geo**	er .. there is some friction .. but there is also the weight of the book .. which has some weight .. but together with friction .. that the wood of the table has .. because it is not smooth .. it is rather rough .. and the book .. er .. its cover .. it is not smooth either .. and so they interlock .. that is the book cannot move on the surface of the table ..	
009	**Int**	what do you mean when you say that they interlock .. what happens then .. /	
010	**Geo**	yes .. er .. the wood might be like this .. also the cover of the book might be like this .. so the cover .. it is as if it fixes a bit .. so friction is created .. and it can't slide down ..	[drawing a wavy line on the table with his finger]

Similarly, (**Nt**) appears to be suggesting that the weight of the book holds it stationary on the surface of the tilted table (010). Furthermore she also attributes a "helping" role of friction (012). Thus, she points out that the "rough" surfaces of the table and the book are "rubbing" together (014), or the "little hills and valleys" of the "rough" surfaces are "catching together" and it is "as if they are stuck". This creates friction, which hods the book in its place (016).

010	**Nt**	er .. the book with its weight holds itself on the table ..
011	**Int**	what do you mean .. /
012	**Nt**	er ..4.. with its weight it presses the table .. umm .. there is also some friction here.. which helps it hold up there ..
013	**Int**	how do you think that friction helps it hold up there .. as you say .. /
014	**Nt**	umm .. the table has .. some rough surface .. let's say .. er .. anyway not so smooth .. er.. the book also has some rough surface .. on its cover .. and these surfaces .. it is as if they are rubbing .. and friction is created ..

015	**Int**	can you describe how do you think that they are rubbing .. /	
016	**Nt**	er .. the book with it force .. er .. its weight .. with the weight that it has .. and that is touching on the table .. with its cover .. which is heavier than a page .. and it looks as if it has little hills and valleys .. and somehow they are touching the rough surface of the table .. and it is as if .. it is catching like this .. as if it gets stuck and holds itself there ..	[trying to represent it with her fingers]

*Two children (**Jn, Di**) are indicating that the nature of surfaces in contact seems to be an important element for the creation of friction. Thus, for them, friction is considered to be surface dependent.*

Hence, (**Di**) appears to be suggesting that the materials that the book or the table are made of, is an important factor in the creation of friction, but "it also has to do with the surfaces" (006 & 007). Thus, if the table is "wooden" the "hills and valleys" of the surfaces "get together" or "interlock with each other" and that hinders the motion of the book (009 & 011), whereas if the table has "plastic laminate" on top it is "smoother" and there is "a greater chance" for the book to slide (013). He also suggests that if the table is lifted higher then the book will start sliding (013).

006	**Di**	.. it depends on what the book is made of .. /
006.5	**Int**	>> umm hmm ..
007	**Di**	.. on whether the book is smooth .. or .. whether it is rough .. and this is also same for the wood .. of the table .. it also has to do with the surfaces
008	**Int**	and what happens here .. / can you describe it .. /
009	**Di**	er .. because if the table is wooden .. and it must be wooden here .. since the book does not move .. umm .. the book cannot move and the table needs to be lifted higher ..
010	**Int**	what happens between the surfaces then .. /
011	**Di**	er.. the book is touching on the table .. but its weight is pulling it downwards .. and so the wood of the table is hindering its motion .. because it is not smooth .. it has little hills and valleys .. which get together .. and it is as if they interlock with each other .. and so friction is created ..
012	**Int**	and what if the table was not wooden .. but it had plastic laminate like this one .. / what would happen then .. /
013	**Di**	er .. there would be a grater chance to slide down .. because the plastic laminate is smoother than wood .. but it also depends on how high the table is lifted .. because if we lift the table higher .. then the book will start sliding ..

Likewise, (**Jn**) indicates that there is friction on the stationary book on the tilted table and this depends on the surfaces. Thus, he points out that friction is created because the surfaces of the book and the table are "rough", whereas if they were "smooth" like "plastic laminate" or "very well planed wood" there wouldn't be "much friction" (010). He points out that friction is created because "the projections of one surface are getting into the cavities of the other" (012).

008	**Jn**	er.. because if there wasn't any friction .. then the book would slide downwards .. er .. yes .. and here we have friction .. which depends on the surfaces ..	
009	**Int**	umm .. what do you mean .. /	
010	**Jn**	er .. the surfaces .. the surfaces of the table and the book .. they are both rough .. and so friction is created .. if they are smooth there won't be much friction .. like a table with plastic laminate .. or very well planed wood ..	
011	**Int**	how friction happen then .. /	
012	**Jn**	umm .. the projections of one surface are getting into the cavities of the other surface .. er.. here that the book is touching the table .. it is as if it holds the book not to side down ..	[pointing at the respective part of the depicted instance]

Only one child (**Ka**) appears to be suggesting that there is no friction keeping the book stationary on the tilted table. Thus, the book remains still because it is not pushed, or the table is not shaken or moved (009). She appears to be considering that friction will only be created when the book starts sliding on the tilted table (007 & 011).

005	**Ka**	er .. I don't think there is any friction holding it there .. /
006	**Int**	why do you think that it doesn't slide and it remains stationary .. /
007	**Ka**	er .. maybe because we don't shake the table .. and that's why the book remains still .. it doesn't slide downwards .. so it cannot create friction ..
008	**Int**	and how do you think that .. it remains still .. /
009	**Ka**	er .. because we don't push it .. or we don't move or shake the table .. it is motionless .. something like stuck ..
010	**Int**	do you think this has to do with friction .. /
011	**Ka**	no .. only if we move the table .. or push the book ... and the book will start sliding .. only then we will have some friction ..

*Five children (**Ge, Ni, Geo, Nt, Ka**) appear to be regarding that when the table is lifted higher the book will start sliding because its "weight will start pulling it more" downwards and the table "won't be able" to hold it any longer, or friction becomes "weaker" and "can't hold it any more". Hence, they appear to be attributing an anthropomorphic characteristic to friction.*

For example, (**Ge**) points out that when the table is lifted higher the book will start sliding (014) because the table "can't hold it any more" and it will "un-grip" (016).

013	**Int**	I see .. if we lift the table a bit higher .. what will happen .. /
014	**Ge**	the book will start sliding ..
015	**Int**	why do you think that happens .. /
016	**Ge**	er .. because the table can't hold it .. any more .. and it will .. un-grip .. it will go .. it will slide downwards ..

Likewise, (**Geo**) appears to be suggesting that when the table is lifted higher the book will start sliding because its weight "is pulling it downwards" and the "rough surfaces" can't "hold" it motionless up on the table any longer (013).

011	**Geo**	.. but if we lifted the table higher ..
012	**Int**	what would happen then .. /
013	**Geo**	if we lifted it higher .. then the book would start sliding .. it should start sliding .. because the book has some weight .. and if we lift the table high enough .. then their rough surfaces.. cannot hold the book in its place .. and its weight is pulling it more downwards ... and so it will start sliding ..

*Two children (**Joh, Di**) appear to be considering some friction at the touching points of the legs of the table with the ground and/or the box.*

For example, (**Di**) points out that there is "some friction" at the touching points of the legs of the table with the ground, because they are "holding" the table "at a certain point" and they don't let it "slip" (017).

016	**Int**	I see .. is there anything else you would like to add here .. /
017	**Di**	umm .. yes .. there is also some friction at the legs of the table .. which are touching the ground .. because they are holding themselves at a certain point and they don't slip .. otherwise the table wouldn't be able to hold on the box .. umm .. nothing else ..

*Three children (**Ba, Geo, Di**) appear to be symbolising friction with an arrow that is pointing downwards, because friction somehow "sticks" the book onto the table.*

For example, (**Ba**) is indicating that the arrow of friction should be pointing downwards because "friction is like sticking the book onto the table" (015).

014	**Int**	I see .. if I asked you to symbolise friction with an arrow .. which way would that arrow point to .. /	
015	**Ba**	er .. probably this way .. because friction is like sticking the book onto the table .. that's what I think ..	[forming an arrow with her finger. pointing towards the ground]

(**Joh**) appears to be using two arrows, one pointing downwards and one upwards, to symbolise friction, because he suggests that not only the book is being held on the table, but the "irregularities" of the table also "help" it to remain stationary (017).

016	**Int**	If I asked you to symbolise friction on the book with an arrow .. how would you symbolise it .. /	
017	**Joh**	er .. probably like this .. downwards .. because I think that the book is being held on the table this way .. umm .. but also ..4.. I will draw an arrow upwards .. because the irregularities of the table are also helping the book to hold stationary ..	[forming with his finger two arrows respectively]

Only (**Bi**) is indicating an arrow pointing upwards along the surface of the table because she claims that friction is "resisting" the weight of the book which "is pulling it down the table" (014).

013 **Int** if I asked you to symbolise friction with an arrow .. which way would that arrow point to .. /

014 **Bi** er.. that way .. up the table .. because it is resisting the weight of the book that is pulling it down the table .. [forming an arrow along the surface of contact of the book and the table pointing upwards along the table]

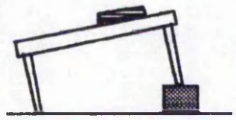
Interview Card	Groupings of conceptions and alternative conceptions	NoR
	• **There is friction along the interface of the book and the table because they are rough surfaces and they "interlock" or "get into one another".**	*4*
	• **The weight of the book somehow "helps" friction to hold it stationary on the surface of the tilted table.**	*3*
	• **Friction depends on the nature of surfaces in contact. Thus the book will slide down easier if the table is covered with plastic laminate or if its surface is well planed.**	*2*
	• **Friction will only be created when the book starts sliding.**	*1*
	• **If the table is lifted higher, then the book will start sliding because its weight is pulling it "more downwards" or "friction won't be able to hold it back" any more.**	*5*

Table 5.4.1: A synopsis of the groupings of conceptions and alternative conceptions from the analysis of the "book on the tilted table" instance with respective numbers of children's responses (*NoR*).

5.4.b. The card with 'the person walking along the street' instance

*Most of the children (**Ge, Ni, Jn, Geo, Nt, Bi, Di**) appear to be thinking of friction between the surfaces of the shoes and the ground in terms of "gripping", "catching" or "fixing" together, due to their roughness. Two children (**Bi, Di**) are referring to the analogy of the jigsaw puzzle in order to describe what happens between the surfaces.*

Thus, (**Ge**) appears to be considering that there is friction between the shoes of the person and the ground because they are "rough surfaces" with "little hills and valleys" and they "grip" together (026 & 028). Hence, friction is exerted and the child manages to walk on the road (030).

026 **Ge** er .. there is friction .. at his shoes and the floor er .. on the road that he is walking ..

027 **Int** what do you mean .. / .. how is friction there .. /

028 **Ge** er .. with his shoes .. as he is walking .. the shoes have a rough surface just like mine .. it is as if the have little hills and valleys and they grip on the road .. [pointing at his shoes]

029 **Int** what do you mean .. the shoes grip on the road .. /

030 **Ge** er .. the shoes .. and the road has little hills and valleys .. it has a rough surface .. and the shoes grip on it .. and they are exerting some friction .. and the child can walk on the road ..

Similarly, (**Bi**) points out that the shoes are "rubbing" on the ground and they are "gripping" (020). This is because "there are no perfectly smooth surfaces" because they are "full of cavities and projections", which appear to be gripping just like "the jigsaw puzzle" (022).

020	**Bi**	er .. as he is walking it is like .. the shoes are rubbing on the ground .. er .. because the shoes are gripping on the ground and so he doesn't slip ..	
021	**Int**	can you describe .. how do you think that the shoes are gripping .. /	
022	**Bi**	er .. because there are no perfectly smooth surfaces .. so the shoes and the road .. are full of cavities and projections .. and as the shoes are touching the ground .. it is as if they are gripping .. just like the jigsaw puzzle .. that's how it happens ..	

(**Nt**) indicates that there is friction "exerted" between the surfaces of the shoes (024) and the ground which has "crannies and valleys". She suggests that they "interlock" with each other, creating friction, which "enables" the person to walk (026).

024	**Nt**	er .. at his shoes .. as he is walking .. a friction is exerted at his shoes .. there..	[pointing under the shoes]
025	**Int**	how do you think that friction is exerted there .. /	
026	**Nt**	er .. with his shoes .. umm .. his shoes .. have a rough surface .. with crannies and valleys .. and the road has little hills and valleys .. because it is never very smooth .. and it is as if the interlock a bit .. the person does not slip to fall down .. there is friction which enables him to move ..	

*Three children (**Ba, Ka, Joh**) appear to be considering the "rubbing" of surfaces as an important element for the creation of friction along the interface of the shoes and the ground.*

Hence, (**Ba**) appears to be suggesting that the shoes of the person are "rubbing" on the surface of the ground "creating friction", but she also points out that it depends on "what kind of shoes we are wearing" (021). Thus, "sports shoes" appear to be having "crannies" and they "rub and grip a lot" on the ground, whereas normal shoes don't grip as much (023). She suggests that the same happens with the ground, which means that it will be easier to slip on "polished marble" than on the "asphalt" (026).

021	**Ba**	er .. with her shoes .. as we are walking with our shoes .. they are rubbing on the road creating friction ..4.. it also depends on what kind of shoes we are wearing ..
022	**Int**	what do you mean .. /
023	**Ba**	er .. sports shoes for example .. they have like crannies .. and they can rub and grip a lot on the ground .. more than normal shoes .. they hold on .. and it is more difficult to slip with the sports shoes ..
024	**Int**	I see .. any thing else you would like to add here .. /
025	**Ba**	er .. the ground ..
025.5	**Int**	>> what happens with the ground ..
026	**Ba**	.. er .. that also holds us better if it is asphalt .. whereas we can slip more easily .. like on polished marble .. when we play at home ..

Likewise, (**Ka**) appears to be pointing out that the shoes of the person are "rubbing" on the ground creating friction, because the person is moving ahead (019 & 021). This is because the surfaces of the shoes and the ground are "rough" and they are "rubbing" as the child is moving, or somehow they "catch and fix" with each other (023).

019	**Ka**	er .. when the person is walking .. somehow the shoes are rubbing on the ground .. and so he can move ahead .. whereas if he wouldn't be able to move there wouldn't be any friction created ..	
020	**Int**	I see .. can you show me the points that you think that friction exists here .. /	
021	**Ka**	er .. yes .. there is friction there and there ..	[pointing under the shoes at the area of contact with the ground]
022	**Int**	what do you think that happens there .. /	
023	**Ka**	er .. there is friction .. that means .. the shoes of the child are rubbing on the ground .. while he is moving .. because we have two rough surfaces .. that somehow catch and fix with each other .. like this .. and .. that's how friction is created ..	[representing it with two fingers]

*Five children (**Ge, Jn, Geo, Joh, Di**) appear to be considering that friction is reduced when the road has oil (**Ge, Di**) and/or water (**Jn, Joh**). Similarly, when the person is walking on ice it is very easy to slip and fall, due to very little friction created (**Geo**).*

For example, (**Jn**), appears to be suggesting that "there is not much friction" when the road is covered with "oil or water" (019), because the surfaces seem to be "losing their roughness" (021). Thus, the shoes are not "touching firmly" on the road and as a result the person will slip (023).

019	**Jn**	er .. the person might slip and fall .. when the road is covered with oil or water .. it has happened many times ..
020	**Int**	what happens then .. /
021	**Jn**	then .. there is not much friction .. because the surfaces .. it is as if they are loosing their roughness .. and so we slip ..
022	**Int**	what do you mean .. they are losing their roughness .. /
023	**Jn**	er .. as we learnt .. friction depends on the roughness of surfaces that are touching each other .. er .. and when the road has oil .. it is as if our shoes are not touching firmly and so we slip .. umm . that's what I think ..

Similarly, (**Di**) indicates that the shoes are "gripping" on the ground because the "projections of one surface are getting into the cavities of the other" and so friction is created (024). But, when the road is covered with oil, it will be difficult to walk, because it looks as if the surface of the road becomes "more smooth" and there will be "less friction" (026).

024 **Di** er .. it is as if the shoes are gripping .. as if they are catching with their roughness .. because the projections of one are getting into the cavities of the other .. and the opposite .. just like the jigsaw puzzle .. we saw when we did those experiments on friction .. and that's how friction is created .. and we can walk .. otherwise we wouldn't be able .. we would slip and fall .. just like when there is oil on the road ..

025 **Int** what happens when there is oil on the road .. /

026 **Di** umm .. then it is like .. it becomes more smooth .. and so friction becomes less .. and we slip ..

(**Geo**) is referring to the case of ice and points out that "ice is very smooth", but most importantly, it becomes smoother due to melted water on its surface and this makes shoes slip on it (025).

025 **Geo** when he is walking on is .. ice is very smooth .. and the water that melts makes it even smoother .. and if the person loses his balance .. his shoes will slip .. and he will fall down for sure ..

*Three children (**Nt, Ka, Di**) appear to be symbolising friction with an arrow that is pointing downwards, alongside with the weight of the person.*

Thus, for example (**Nt**) is indicating that the arrows of friction at each of the shoes of the person should be pointing downwards (028), because "that's how the weight of the child goes", which is "holding him on the road". It appears to her, that friction should also be pointing that way (030).

027 **Int** I see .. if I asked you to symbolise friction with an arrow .. how would you symbolise it here .. / [forming two arrows pointing downwards, under the shoes of the person respectively]

028 **Nt** er .. like this .. and like this ..

029 **Int** umm .. downwards .. why do you symbolise them this way .. /

030 **Nt** er .. because that's how the weight of the child goes .. the weight is holding him on the road .. since the road is hard .. and it supports the child .. and so it is like the shoes are sticking onto the road .. and so friction is exerted .. but when he lifts one leg to walk .. there is no friction on that shoe then ..

Only (**Bi**) appears to be suggesting that the arrow of friction is pointing in the opposite direction of the movement of the person, because that is where "he is touching on the road" (023).

022 **Int** if I asked you to symbolise friction with an arrow .. how would you symbolise it here .. /

023 **Bi** umm .. that way .. in the opposite direction that the person is going .. er .. there under his shoes .. because that's where he is touching on the road .. [forming two arrows at the respective points]

Interview Card	Groupings of conceptions and alternative conceptions	NoR
	• **There is friction along the interface of the shoes and the ground because they are "rough" surfaces and they "grip", "catch" or "fix" together.**	*7*
	• **The "rubbing" of the surfaces of the shoes and the ground seems to be an important element for the creation of friction.**	*3*
	• **Friction is reduced when the road has oil, water or ice.**	*5*

Table 5.4.2: A synopsis of the groupings of conceptions and alternative conceptions from the analysis of the "person walking along the street" instance with respective numbers of children's responses (*NoR*).

5.4.c. The card with 'the box on the slope' instance

*Most of the children (**Ge, Ba, Ni, Jn, Bi, Joh, Di**) appear to be considering that the box remains stationary up on the slope, because the surfaces are "rough" and they "grip", "fix" or "interlock together".*

Thus, (**Ni**) indicates that because the board is "rough" and has "little hills and valleys" the box "grips" and remains motionless (031). She describes this gripping with the "little hills of the board", getting into the "little valleys" of the box "and the opposite" (033).

031 **Ni** here .. / .. umm ..4.. because the surface of the board is rough .. it has like little hills and valleys .. and the box .. it has also a rough surface .. and then .. er .. because the board is steady and the truck doesn't move .. er .. somehow the box grips and stays there ..
032 **Int** what do you mean when you say that the box grips .. /
033 **Ni** er .. with the little hills of the board .. they get into the little valleys of the box .. and the opposite .. and so the box stays up there ..

Similarly, (**Bi**) suggests that the box would probably slide down, but friction at the interface of the box and the slope "doesn't let it" (027 & 029). Thus, the "projections" of the box are getting inside the "cavities" of the slope interchangeably and friction is created (031).

027 **Bi** yes .. there is friction here .. it's the box that would probably slide down .. but friction doesn't let it slide ..
028 **Int** where do you think there is friction here .. /
029 **Bi** er .. at the surface of the box that is touching the slope ..
030 **Int** why do you say that .. friction doesn't let it slide .. /
031 **Bi** er .. it is like the table and the book .. the projections of the box are getting inside the cavities of the slope .. umm .. or also the opposite .. and so friction is created ..

(**Joh**) is indicating that in this instance, there is a "similar friction" to that of the "book on the table" instance, since the "interlocking" of the "hills and valley" is happening "again" (033).

031	**Joh**	yes .. there is friction here .. because the wood can hold the box .. as we said in the case of the table and the book .. so here we have a similar friction ..
032	**Int**	what do you mean .. /
033	**Joh**	umm .. as we can see here the board is not so smooth the same with the box .. it is not so smooth either .. so it holds the box and it cannot slide down .. again the hills and valleys of the surfaces .. interlock with each other ..

*Two children (**Geo, Nt**) appear to be considering that the weight of the box "is sticking" it on the slope, by pulling it downwards and in this way, it is probably implied that it "helps" friction.*

Thus, (**Geo**) appears to be suggesting that the weight of the box is "kind of sticking it on the slope" and since the wood of the slope is "always rough" and the slope is not steep enough, it remains stationary (031). Hence, the two surfaces "get fixed" because their "asperities and bumps" are getting into one another, creating friction (034).

031	**Geo**	because the weight of the box is kind of sticking it on the slope .. and the wood of the slope is rough .. it is always rough .. no matter how well planed it is .. and because the slope is not high enough .. because if it was higher .. the box would slide .. because its weight is pulling it downwards ..
032	**Int**	what do you think is happening at the points of contact between the box and the slope .. /
033	**Geo**	er .. as I said before .. the board is rough .. and the box is also rough and when they come in contact .. that is .. when we place the box on the slope ..
033.5	**Int**	>> umm hmm ..
034	**Geo**	.. er .. it is as if it gets fixed there .. the asperities and the bumps are getting into one another .. they fit together and friction is created .. so the box stays where we left it ..

Likewise, (**Nt**) is indicating that the box remains motionless up on the slope because its weight is pulling it downwards and the surfaces in contact are "rough" (038). Thus, they "stick together a bit" because they are "getting into one another", creating friction (041).

038	**Nt**	er .. the box that is on the slope has some weight pulling it downwards .. and with this weight and because the bottom of the box is touching the slope .. it has roughness .. like little hills and valleys ..
038.5	**Int**	>> umm hmm ..
039	**Nt**	.. the same with the slope .. which is usually wooden .. and so they stick together.. a bit .. and friction is created ..
040	**Int**	what do you mean when you say .. they stick together a bit .. /
041	**Nt**	er .. it is like one surface getting into the other creating friction .. and so the box can hold steady and .. it does not slide down ..

*Four children (**Ge, Ba, Ni, Bi**) appear to be indicating that if the slope is lifted higher, the box will start sliding because "friction cannot hold it steady any longer" or its "weight is pulling it downwards". They seem to be suggesting though, that there will still be some friction when the box is sliding.*

Thus, (**Ba**) for example points out that the box will start sliding if the board is lifted higher because "friction will become less" and it "won't be able to hold it there any longer" (031).

031 **Ba** er .. yes .. if we lift the board a bit higher .. then the box will start sliding .. because friction will not be able to hold it .. because it will become less .. you see.. and won't be able to hold it there any longer .. also its weight will pull it towards the ground ..

Similarly, (**Bi**) indicates that there will still be some friction when the box starts sliding down the slope because "it gets hold a bit" and "it will move rather slowly" (032 & 034).

032 **Bi** umm .. if we lift the board a bit higher the box will start sliding ..
033 **Int** and .. when it starts sliding is there any friction then .. /
034 **Bi** umm .. yes I say there is .. because again the box gets hold a bit .. on the slope .. and it won't fall quickly straight down .. it will move rather slowly ..

*Five children (**Ge, Jn, Geo, Nt, Di**) seem to be considering that there is friction at the tyres of the truck, but also at the two edges of the board that are touching on the ground and on the back door of the truck.*

For example, (**Geo**) indicates that there is "a bit of friction" at the tyres of the truck which are "rough" and somehow they "fix" with the ground (036). He is also considering "some friction" at the touching points of the board with the back door of the truck and the ground, again because they are "rough" (037).

035 **Int** I see .. is there anything else you would like to add here .. /
036 **Geo** yes .. here .. at the tyres of the truck .. there is a bit of friction .. because the tyres is also rough .. and it is as if it fixes on the ground .. and holds the truck still .. [pointing at the tyres of the truck]
036.5 **Int** >> umm hmm ..
037 **Geo** .. er .. there is also friction at the back door of the car where the board is touching it .. and there is also some friction at the points that the board is touching the ground .. because the road is rough .. there is some friction exerted there ..

(**Di**) appears to be expressing a more holistic opinion and he suggests that there are "four friction forces", which seem to be exerted at the tyres of the truck, at the two edges of the slope touching the ground and the back door of the truck and along the interface of the box and the slope (034).

034	**Di**	er .. there is friction at tyre of the car .. there where the board is touching at the back door of the truck .. here that the box is touching on the board .. and here that the board is touching the ground .. so we have one .. two .. there .. four forces of friction here ..	[pointing at the respective points on the card]

Only (**Ka**) appears to be suggesting that there is no friction holding the box on the slope because there is no relative motion or "rubbing" between the two surfaces for friction to be created (030 & 034). She mentions that the box remains motionless on the slope because "people have made it to be that way", or the slope is "fixed" in a way that prevents the sliding of the box (032).

030	**Ka**	I don't think there is any friction here .. because the box is not sliding on the surface of the slope .. it is not rubbing on it ..
031	**Int**	umm hmm .. how do you think that the box remains still .. /
032	**Ka**	umm .. it's maybe because people have made it to be that way .. they have fixed the slope .. so the box cannot fall or slide on it ..
033	**Int**	what do you mean .. / .. they have fixed it ..
034	**Ka**	er .. they have put it properly .. so the box cannot slide down .. if they put is a bit higher .. lets say .. then the box would start sliding .. and then friction would happen .. because the surfaces would be rubbing then ..

*Three children (**Ba, Jn, Nt**) appear to be suggesting that the arrow of friction is pointing downwards, alongside with the arrow of weight because somehow it "sticks" or "helps to stick" the box on the slope.*

Thus, (**Jn**) for example, points out that the arrow of friction has a downwards direction because it pushes the box alongside with the weight and it is "as if it sticks it on the slope" (033).

032	**Int**	if I asked you to symbolise with an arrow .. the friction on the box .. how would you symbolise it .. /	
033	**Jn**	umm .. probably like this .. because it is as if it pushes the weight of the box downwards .. as if it sticks it on the slope .. and does not let it slide downwards ..	[forming an arrow which is pointing downwards]

(**Bi**) appears to be considering that the arrow of friction should be pointing upwards along the surface of the table because "it is holding the box there", preventing it from sliding (045).

044 **Int** if I asked you to symbolise friction on the box .. with an arrow .. how would you symbolise it ..

045 **Bi** this way .. pointing up the table .. because again .. er .. it is holding the box steady there .. and it doesn't let it slide .. [forming an arrow with the respective direction]

(**Joh**) seems to be symbolising friction with two arrows, one pointing downwards and one pointing upwards. The first seems to be related with the weight of the box and the latter with the surface effect of the slope (035).

034 **Int** well .. if I asked you to symbolise friction .. on the box .. with an arrow .. how would you symbolise it ..

035 **Joh** umm .. this way .. and that way .. because it is the weight which is holding it .. and the slope .. which is also holding it .. [forming one arrow pointing upwards and one pointing downwards]

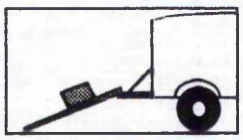
Interview Card	*Groupings of conceptions and alternative conceptions*	*NoR*
	• **The box remains stationary up on the slope because both of the surfaces are "rough" and they "grip", "fix" or "interlock" together.**	*7*
	• **The weight of the box is "helping" friction by sticking it on the surface of the slope.**	*2*
	• **If the slope is lifted higher the box will start sliding because "its weight is pulling it downwards" or "friction cannot hold it steady any longer". Nevertheless, there will still be "some friction".**	*4*
	• **There is also friction at the tyres of the truck and at the points of contact of the slope with the ground and the back door of the truck.**	*5*
	• **There in no relative motion or "rubbing" between the box and the surface of the slope, so there is no friction keeping it stationary.**	*1*

Table 5.4.3: A synopsis of the groupings of conceptions and alternative conceptions from the analysis of the "box on the slope" instance with respective numbers of children's responses (*NoR*).

5.4.d. The card with 'the block of wood on the table' instance

*Most of the children (**Ge, Ba, Jn, Geo, Bi, Nt, Di**) appear to be considering that there is friction at the area of contact, between the block of wood and the table, which "helps" it to remain stationary. They are also suggesting that the pulling force from the weight, hanged at the end of the string, is not enough to initiate the sliding of the block.*

Thus, (**Ge**) points out that friction is "exerted" by the table and it is "keeping" the block stationary, because there is not enough weight to start it sliding (043). This is

because the surfaces are "rough" and they "grip" one over the other (045). He suggests that the block will start sliding if it is pulled with one fourth of its weight and when the table is covered with sandpaper, the pulling force must be "more than half of the weight of the block" (047).

043 **Ge** er .. friction is keeping it on the table .. which is exerted by the table .. but also because the weights that we have hung are not enough to pull it along the surface of the able ..
044 **Int** how do you think that the friction exerted by the table .. as you say .. keeps it there .. /
045 **Ge** er .. the surfaces are rough and they grip .. one over the other .. and so friction is created ..
046 **Int** why do you think that the weight we have hung cannot pull the block on the surface of the table .. /
047 **Ge** er .. because it is not enough .. as we experimented in class the other day .. we found out that the weight we have to hang is about one fourth of the weight of the block .. and if we have sandpaper it is more that half of the weight of the block .. otherwise it cannot start sliding..

Likewise, (**Ba**) indicates that the block of wood and the table "are not smooth surfaces" since they have "little hills and valleys" and so they "grip on each other". She also suggests that there is not enough weight to start the sliding of the block and that seems to be another reason for its motionless condition (039). Hence, "more weights" need to be added for the block to start sliding (040), especially on sandpaper, because there, the surfaces are "very rough" and they grip more (042).

039 **Ba** er .. at the points that the block is touching the table .. there is some friction because .. er .. the block and the table are not smooth surfaces .. they have little hills and valleys .. and so .. it is as if they grip with each other .. but .. also the weight that we have hung there is not much .. and it cannot pull the block with a lot of force ..
039,5 **Int** >> umm hmm ..
040 **Ba** .. er .. and so it cannot slide on the table .. umm .. and if the block is on sandpaper .. it is even more difficult to move .. we need to add some more weights .. because the block rubs more on the sandpaper ..
041 **Int** why do you think that the block rubs more on the sandpaper .. /
042 **Ba** er .. because it is rougher .. er .. the surfaces are very rough and they grip more .. that's what I think ..

(**Nt**) is also indicating that one fourth of the weight of the block is needed for it to start sliding on the surface of the table, but there is also friction that is "helping" it to remain motionless (050). Hence, the "rough" surfaces of the block and the table have "little hills and valleys" and they "grip", just like "the two pieces of the jigsaw puzzle" (052).

050 **Nt** er .. the weight cannot pull the block along the table .. if we want to slide it we have to add some more weight .. about one fourth of the weight of the block .. as we did some days ago .. but also friction is helping it ..

051 **Int** I see .. how do you think that friction is helping it .. /
052 **Nt** umm .. the block of wood has a rough surface .. with little hills and valleys .. and if we have sandpaper there are more of these .. and they grip .. just like the pieces of the jigsaw puzzle .. and so friction is created ..

*Two children (**Ni, Joh**) appear to be considering that the weight of the block is holding it stationary on the table, because the block is "heavier" than the pulling force of the weights. In this way, it is more or less "helping" friction.*

(**Ni**) appears to be indicating that the block remains motionless because the block of wood is "heavy". Also, there is not enough weight to pull it along the table and the surfaces are rough, so "some friction" is exerted (041). Hence, he suggests that the block of wood "can hold" the pulling exerted by the weights, "with its weight" (043) and in this way, it can "help" the block remain stationary, more than friction does (045).

041 **Ni** because the block of wood is heavy and the weight that we hang .. not so much .. the block cannot move .. er .. also the table has a rough surface .. same as the block .. and where they touch .. and some friction is exerted ..
042 **Int** why do you think that the block does not move from its place .. /
043 **Ni** er .. because the block is heavy .. and the weight we have hung is not heavy enough to pull it .. the block I mean .. it can hold the weight ... er .. with its weight ..
044 **Int** umm hmm .. and the friction you mentioned before .. /
045 **Ni** umm .. friction is as if it helps it a bit to hold there .. but I think that its weight is helping it more to stay there .. because it presses the block on the table ..

In a similar way, (**Joh**) points out that the block of wood is "heavier" than the pulling force of the weights, and nearly one fourth of the weight of the block is required for it to start sliding (048). Hence, it is "its weight and friction" that keep the block motionless on the table (050).

048 **Joh** er ..4.. we can observe that the block of wood is heavier than the weight we have hung .. so it cannot move the block .. only if we hang some more weight.. nearly one fourth of the weight of the block .. then the block will start sliding..
049 **Int** what do you think .. holds the block motionless .. /
050 **Joh** er .. its weight and friction ..

Only (**Ka**) appears to be hesitant in recognising "a little bit", or "some" friction (050) along the interface of the block of wood and the table (048 & 050). Thus, there will be "some friction" when the block starts sliding (046), but in this case it remains stationary because "there is not enough weight" to pull it (048). Also, the weight of the block somehow "sticks" it on the table (050).

046 **Ka** er .. as we experimented .. if the weight we hang .. is about one fourth of the weight of the block .. then the block will start sliding .. and then there will be some friction ..
047 **Int** what about now .. that the block is not moving on the table although there is a pulling force exerted to it .. /
048 **Ka** er .. I don't think there is that much friction .. maybe a little bit that is helping it hold on the table .. but I think that it doesn't move because there is not enough weight pulling it .. to start sliding ..
049 **Int** .. and that is the only reason that you think .. that the block remains stationary on the table .. /
050 **Ka** yes . and also its weight .. which is as if it sticks it on the table .. but there might be some friction there as well I am not really sure ..

*Three children (**Jn, Geo, Di**) seem to be indicating that the arrow of friction is pointing downwards alongside with weight, because they are both "pressing" or "sticking" the block on the surface of the table.*

For example, (**Di**) is suggesting that the arrow of friction should be pointing downwards because it looks "as if it is pressing" the block downwards, together with its weight and in that way it is "resisting" the pulling force "from the weight we have hung" (050).

049 **Int** how would you symbolise the force of friction here .. /
050 **Di** umm .. like this pointing downwards .. because it is as if it is pushing the block of wood on the table .. as if it is pressing it together with its weight downwards .. so it is resisting to the force from the weight we have hung .. [forming an arrow pointing downwards]

*Two children (**Ge, Joh**) appear to be regarding that the arrow of friction should be pointing to the left, in the opposite of the potential movement of the block.*

For example (**Joh**) indicates that the arrow of friction should be pointing "in the opposite direction of the pulling force of the weight", because it is "hindering" its potential movement, in a way.

051 **Int** if I asked you .. to symbolise friction with an arrow how would you symbolise it .. /
052 **Joh** er .. it will be an arrow this way .. in the opposite direction of the pulling force of the weight .. because friction is hindering it from moving that way .. [forming an arrow pointing to the left]

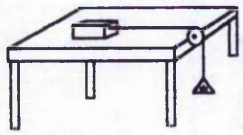
Interview Card	Groupings of conceptions and alternative conceptions	NoR
	• **There is friction at the points of contact of the block of wood with the surface of the table which "helps" it to maintain its motionless condition. Also, there is not enough pulling force from the weight.**	*7*
	• **The weight of the block is "helping" friction to keep it stationary on the surface of the table.**	*2*
	• **There might be some friction, but the block remains unmoving because there is not enough pulling force and its weight is "sticking" it on the table.**	*1*

Table 5.4.4: A synopsis of the groupings of conceptions and alternative conceptions from the analysis of the "block of wood on the table" instance with respective numbers of children's responses (*NoR*).

5.4.e. The card with 'the slow-down of the bicycle' instance

*All of the children appear to be considering that there is friction at the touching points of the tyres and the ground, which is retarding the motion of the bike and eventually "puts it into halt". They are also suggesting that since the person is not pedalling any more the bicycle will slow down faster. Five children (**Ba, Bi, Nt, Joh, Di**) describe the phenomenon by pointing out that the "crannies" of the "rubbing" tyres are "hitting" on the "projections" or "irregularities" of the ground, and thus friction is created.*

For example (**Ni**) indicates that there is friction at the tyres because they have "crannies" and as they "spin round", they rub with the "rough" surface of the road (051), "catching" with each other. In this way, they rub and create friction (053).

051 **Ni** er .. there is friction because .. the tyres have .. like crannies .. and the road is also rough .. and so they rub .. when they spin around .. and if the child has stopped pedalling .. then the bike is loosing its speed .. and the bike will gradually stop ..
052 **Int** how do you think that the tyres are rubbing .. / .. as you say ..
053 **Ni** er.. as the bike goes .. the tyres are rolling on the road .. er .. and since they are both rough surfaces .. er.. it's as if .. how can I say it .. as if the catch with each other .. and so they rub .. creating friction ..

In a similar way, (**Ba**) points out that the tyres are rubbing with the ground, as they are spinning round (048), which means that the "cavities" and the "little hills" of the tyres are "hitting" on the roughness of the road, so the bike will gradually "lose" its speed, provided that the child is not pedalling any more (050). She is also

considering that if the road is "bad", or a "dirt road", the tyres will be "hitting a lot more with its roughness" and the bike will stop "a lot faster" (052).

048 **Ba** er .. because as the tyres are rubbing .. as they are spinning and .. they touch the ground .. er .. they make it go slowly .. and then stop .. how do you think that the tyres are rubbing as you say .. / can you describe that a bit .. /

049 **Int** er .. the tyres of the bike .. are also very rough .. they have cavities and .. like little hills .. and they interlock with the rough surface of the road .. and it is as

050 **Ba** if they are hitting on the roughness of the road .. and so the bike is gradually loosing its speed .. that is **if** the child has stopped pedalling ..

051 **Int** I see anything else you would like to add here .. /

052 **Ba** umm .. yes if the road is bad .. or a dirt road .. er .. then the tyres are hitting a lot more with its roughness .. and the bike will stop a lot faster .. I have observed it happening this way ..

Likewise, (**Bi**) seems to be regarding that since the tyres are "rubbing" on the road and the child is not pedalling any longer the speed of the bike will be reduced (054). This rubbing occurs when the tyres are "hitting" the "projections" of the road and they are slowing down "bit by bit" (056). She points out though, that if the person uses the brakes, the bike will stop "faster". This is because the brakes "grasp" the wheel, slowing it down "faster" and "easier" (058).

054 **Bi** yes .. it is reducing the speed of the bike .. because the tyres are rubbing on the road .. and the child is not pedalling any more .. or using the brakes ..

055 **Int** what do you mean when you say that the tyres are rubbing on the road .. /

056 **Bi** er .. as they spin.. they rub .. I mean .. it is as if they are hitting the projections of the road and they are slowing down bit by bit .. and gradually the bike will stop moving .. umm of course it would stop faster if he used the brakes ..

057 **Int** what would happen then ..

058 **Bi** then .. a lot of friction would be exerted from the brakes on the wheel .. as they grasp it .. and they will stop the bike faster and easier..

There is one child, (**Ka**) who is suggesting that the bike "wouldn't be able to move" if there was no friction at the tyres, which are "constantly rubbing" on the ground, reducing the speed of the bike (053), since the person is not pedalling any more (056). Thus, this rubbing of the tyres on the ground, enables them to "keep moving", but at the same time, the friction which is created because of the "rough" surfaces that "fix together" (055), is hindering the motion of the bike (056).

053 **Ka** er .. if there was no friction the bike wouldn't be able to move forward .. but because the tyres are constantly rubbing .. as they turn round and touch the ground .. the speed of the bike will become less for sure .. it cannot keep moving for ever ..

054 **Int** I see .. what do you mean when you say the tyres are rubbing on the ground .. /

055 **Ka** er .. as the tyres are rubbing on the ground .. because of that the bike can keep moving .. but also this friction is happening because we have rough surfaces just like the tyres and the ground .. and as they touch they fix together .. and so friction is created ..

055.5 **Int** >> umm hmm ..
056 **Ka** .. er .. but this friction .. is also hindering the bike to move .. and gradually it will stop .. **since** the child is not pedalling any more ..

Only (**Jn**) is indicating that apart from the friction on the tyres, which is created due to their rubbing with the ground (049), it is "also the weight" of the bike, which is constantly keeping it "in contact with the ground". In this way, the "weight" appears to be creating the necessary conditions for friction to "exist", at the areas of contact (050.5).

049 **Jn** er .. it because the tyres of the bike are touching on the road .. and as they spin round .. they rub .. because the road is not smooth .. and so the bike will stop going .. since the child is not pedalling any longer .. so he doesn't give it any more force to move ahead ..
050 **Int** I see ..
050.5 **Jn** >> it is also the weight of the bike .. which is constantly keeping the bike in contact with the road .. and so friction can exist there .. between the tyres and the ground ..

*Six children (**Jn, Geo, Nt, Ka, Joh, Di**) are also considering the existence of friction at various points of surfaces in contact, such as the saddle, the pedals, the handlebars and the chain.*

For example (**Geo**) appears to be considering friction at the pedals, because they are "rough" and they create friction with the shoes, which are also "rough" and so, they don't slip on the pedals (056). He is also suggesting that there is friction at the saddle and if the person used the brakes there would be "another friction" there as well. This is because the "little pieces of rubber", that the brakes have, "grip" on the wheel and create friction, which "will stop the bike a lot faster" (058).

055 **Int** umm .. do you think there is friction anywhere else in this case .. /
056 **Geo** yes .. as the child is stepping on here .. the pedals .. they are rough .. same as our shoes .. and so friction is created .. that's why our shoes don't slip on the pedals .. [pointing at the pedals]
056.5 **Int** >> umm hmm ..
057 **Geo** .. er .. there is also friction at the saddle where the child is sitting .. and so he doesn't slip to fall down .. also if he used the brakes there would be one more friction there .. because the little pieces of rubber that the brakes have .. they are gripping on the wheel and there is friction created .. and the bike will stop a lot faster ..

Two children (**Geo, Di**) appear to be suggesting that the arrow of friction will be pointing downwards, alongside with the arrow of weight, under both of the tyres.

(**Di**) for example, is suggesting that the two arrows of friction, one for each wheel respectively, should be pointing downwards, because "again friction is pushing the bike on the ground together with its weight" (059).

058	**Int**	if I asked you to symbolise friction with an arrow .. how would you symbolise it here .. /	
059	**Di**	er .. I would symbolise it with two arrows .. one this way for this wheel and one the same way for the other wheel .. because again friction is pushing the bike on the ground together with its weight ..	[forming one arrow pointing downwards for each wheel respectively]

(**Geo**) appears to be symbolising friction with two arrows on each tyre, one pointing downwards and one pointing upwards, "from the ground", because they are "catching" on the ground (054).

053	**Int**	if I asked you to symbolise friction at the wheels of the bike .. with an arrow .. how would you symbolise it here .. /	
054	**Geo**	er .. with two arrows .. one pointing downwards .. from each tyre .. and one pointing upwards .. again from each tyre .. from the ground .. as they are catching on the ground ..	[forming two arrows for each tyre respectively]

Interview Card	*Groupings of conceptions and alternative conceptions*	*NoR*
	• **There is friction at the touching points of the tyres and the ground, which slows down the bike and eventually stops its motion.**	*10*
	• **This is because the crannies of the tyres are "hitting" on the "projections" or "irregularities" of the ground.**	*5*
	• **The bike wouldn't be able to move without friction and the constant "rubbing" of the tyres with the ground.**	*1*
	• **The weight of the bike is constantly keeping the tyres in contact with the ground, providing, in this way, the necessary conditions for friction to be created.**	*1*
	• **There is also friction at the saddle, the pedals, the handlebars and the chain.**	*6*

Table 5.4.5: A synopsis of the groupings of conceptions and alternative conceptions from the analysis of the "slow-down of the bicycle" instance with respective numbers of children's responses (*NoR*).

5.4.f$_1$. The card with 'the person going down the slide' instance

*Seven children (**Ba, Ni, Jn, Nt, Ka, Joh, Di**) appear to be considering that the child is "rubbing" with the slide, at the respective points of contact. This creates friction which slows down the sliding of the child.*

For example, (**Jn**) is suggesting that there is friction at the points of contact of the child with the slide (054), that is "at his shoes and where his buttocks are touching the

slide" (056). He points out that the clothes and the shoes are "rubbing" with the slide and they create friction (060), which slows down the child, "as if it holds him back a bit" (058).

054 **Jn** yes .. there is friction at the points of contact of the child with the slide ..
055 **Int** where do you mean .. /
056 **Jn** er .. at his shoes .. and where his buttocks are touching the slide ..
057 **Int** so .. what do you think is happening there .. /
058 **Jn** er .. they rub .. the clothes and the shoes are rubbing with the slide .. and so .. that slows down the child .. to reach the end of the slide .. it as if it holds him back a bit ..
059 **Int** what holds him back .. /
060 **Jn** er .. friction of course ..

Likewise, (**Nt**) appears to be suggesting that there is friction at the "rubbing" surfaces of the child with the slide (070), that is "the trousers and her shoes" (072). So friction is created because the trousers have a "rough" surface and they are "rubbing" or "hitting a bit" with the slide, which is also not "smooth" or has "little hills and valleys" (074).

070 **Nt** er .. there is friction .. between the child and the slide .. I mean .. at the points where the child is rubbing when she is sliding down ..
071 **Int** at which points .. / .. can you describe .. /
072 **Nt** yes .. at the trousers of the child .. and at her shoes ..
073 **Int** how do you think that friction exists there .. /
074 **Nt** er .. the trousers of the child have a rough surface .. er .. the slide is also a rough surface .. it might look smooth but it has little hills and valleys .. and the trousers that are rubbing on the slide .. it is as if they are hitting a bit .. on the surface of the slide .. and so friction is created ..

*Two children (**Ge, Geo**) appear to be considering that the weight of the child is somehow pushing him or her on the slide, and in this way, it is "helping" friction, which slows down the sliding of the child.*

Thus, (**Ge**) is indicating that when the child is sitting on the slide his/her weight is making him/her "touch" on the surface of the slide, because the weight is pulling him/her downwards (063). Furthermore, because of the weight and the "rubbing" of the child on the surface of the slide, friction is exerted at the points of contact with the slide (065), which "doesn't let the child go down very quickly" (063). Hence, he appears to be viewing "weight" as a necessary condition for the contact of surfaces and the creation of friction.

063 **Ge** umm .. when he is sitting on the slide .. the weight .. er.. friction is happening because of his weight which is making him touch the slide .. because it is pulling him downwards .. and so friction doesn't let the child go down very quickly .. he is rubbing .. so with the help of the weight of the child some friction is exerted .. some friction with the slide ..
064 **Int** where do you think that this friction is exerted .. /
065 **Ge** er .. on the slide .. as the child is going down .. er.. at his trousers . and his shoes .. er .. at the points of contact of the child with the slide ..

(**Geo**) seems to be regarding that the weight of the child "is pulling him downwards" and somehow it is "sticking him on the slide", but there is also friction exerted, due to "rubbing" surfaces, which "only slows him down a bit" (063). He points out that friction is created because the slide is "never absolutely smooth". It has some "crannies" and that is where friction is exerted. This wouldn't happen on ice, because "there is very little friction" there (064).

063 **Geo** umm .. the trousers of the child are rubbing with the slide .. and his shoes .. they are exerting a bit of friction as well but because the weight of the child is pulling him downwards .. kind of sticking him on the slide .. he starts sliding .. and friction only slows him down a bit ..
063.5 **Int** >> umm hmm ..
064 **Geo** .. er .. because the slide is never absolutely smooth .. it has some crannies .. and so friction can be exerted .. whereas if he slid on ice .. then he would go further .. because there friction is very little .. and he may also hurt himself badly .. *(cough)*

Only (**Bi**) appears to be suggesting that friction depends on the length of the slide (062). Thus, when the slide is a long one, friction "will be less", because the child will be going down with a lot of speed, so "he will be rubbing less". On the contrary, if the slide is a "small" one, the child will be going down slowly, because there doesn't seem to be enough time to "go down faster" and consequently, he/she will be "rubbing more" (064). She is also the only child who, in this instance, is symbolising friction with an arrow pointing upwards along the surface of the slide because "it is kind of stopping the child from going down fast" (068).

062 **Bi** yes there is friction here .. but it depends on how long the slide is ..
063 **Int** why do you say that .. /
064 **Bi** er .. because if the slide is a long one .. then the child will slide down with a lot of speed and so .. there will be less friction .. because he will be rubbing less .. whereas if the slide is a small or a short one .. the child will slide slowly .. he doesn't have time to go down faster .. and so he rubs more ..
065 **Int** I see .. where do you think that friction exists.. /
066 **Bi** er .. at the points of contact of the child and the slide .. that is the shoes .. and where he is sitting ..
067 **Int** how would you symbolise friction with an arrow here .. /
068 **Bi** umm .. like this .. because it is kind of stopping the child from going down fast .. [forming an arrow pointing upwards along the surface of the slide]

*Five children (**Ba, Jn, Ka, Joh, Di**) appear to be symbolising friction with an arrow pointing downwards, which is somehow "sticking" the child on the slide, alongside with the weight.*

For example (**Joh**) is symbolising friction with an arrow pointing downwards because he suggests that it is somehow "sticking" the child on the slide "together with" his/her weight (074).

073	**Joh**	if I asked you to symbolise friction with an arrow .. how would you symbolise it here .. /	
074	**Int**	er.. probably like this .. because together with the weight of the child .. it is as if it is sticking it on the slide ..	[forming an arrow from the child pointing downwards]

Similarly, (**Di**) is symbolising friction with a downwards pointing arrow because it is as if "it is sticking him, a bit, on the slide" (066). But, he appears to be suggesting that friction is different from weight, because it is pulling the child "as if it is holding him back", whereas the weight is pulling the child "only downwards" (068).

065	**Int**	how would you symbolise friction with an arrow here .. /	
066	**Di**	this way .. downwards .. because it is pushing the child as if it is sticking him .. a bit .. on the slide ..	[forming an arrow from the child pointing downwards]
067	**Int**	is friction then different from the weight of the child .. /	
068	**Di**	yes .. because it is pulling it as if it is holding him back .. whereas the weight .. is only pulling the child downwards .. that's what I think ..	

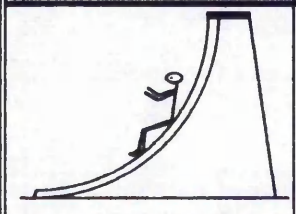
Interview Card	*Groupings of conceptions and alternative conceptions*	*NoR*
	• **The child is "rubbing" on the surface of the slide, creating friction, which slows down his/her sliding.**	*7*
	• **The weight of the child is somehow pushing him/her on the slide and in this way, it is "helping" friction.**	*2*
	• **Friction depends on the length of the slide. Thus, friction will be less for a "long slide" because the child will be going down fast and consequently "he will be rubbing less".**	*1*

Table 5.4.6: A synopsis of the groupings of conceptions and alternative conceptions from the analysis of the "person going down the slide" instance with respective numbers of children's responses (*NoR*).

5.4.f$_2$. The card with 'the person holding steady with the hands up on the slide' instance

*Eight children (**Ba, Ni, Jn, Geo, Bi, Nt, Joh, Di**) appear to be considering that there is friction exerted at the points of contact of the child with the slide, but especially at*

the hands of the person, which are "held" and "pressed" at the sides of the slide, "with lot of force", creating more friction.

For example, (**Jn**) is indicating that there is friction (066) at the "points of contact" of the child and the slide, that is, the shoes, the buttocks and the hands, where "a lot of force" is exerted to hold the child steady up on the slide (068). Hence, the child is "holding tight" at the sides of the slide, with "a lot of force", or "he is pressing" his/her hands with "a lot of strength" and they "grip", creating "one more friction" than the previous case (070).

066 **Jn** yes there is friction here ..
067 **Int** where do you think it exists .. /
068 **Jn** er .. at the points of contact with the slide .. I mean his shoes .. his buttocks and his hands .. where he is exerting a lot of force to hold himself up on the slide ..
069 **Int** what do you think happens there .. at his hands .. /
070 **Jn** er .. as he is holding tight on the slide .. he is exerting a lot of force .. he is pressing them with a lot of strength and it is as if they are gripping on the slide .. and so friction is created .. one more friction from the previous picture ..

Similarly, (**Nt**) is suggesting that the child is exerting "some friction" at the sides of the slide, because "she is holding with her hands" there (076). Thus, she points out the that the child "has to reinforce friction a lot" by exerting "a lot of force" with the hands "otherwise she will slip" (078).

076 **Nt** er .. there is friction here because he is holding with her hands at the sides of the slide .. and so she is exerting some friction which helps her to remain motionless ..
077 **Int** how do you think that friction is helping her .. /
078 **Nt** er .. with her hands she has to reinforce friction a lot to remain still .. umm she has to exert a lot of force .. at her hands .. otherwise she will slip

(**Ge**) appears to be consistent in considering the "helping" role of weight in the contact of surfaces and the creation of friction. Thus, he suggests that because of weight, the child "is touching on the surface of the slide" and in this way "she is rubbing a bit". But, there is also some friction exerted by the hands, which are holding at the sides of the slide (067).

067 **Ge** er .. yes there is some friction here .. because again with the help of weight .. the child is touching on the surface of the slide .. and so she is rubbing a bit .. but she is also holding with the hands exerting some friction on the slide ..

Only (**Ka**) appears to be suggesting that there would be friction only if the child was sliding, so she seems hesitant to recognise the existence of friction when the child is

motionless up on the slide (072 & 074) . She points out that the child has to "grasp" the sides of the slide "with a lot of force", in order to remain stationary. Nevertheless, there will "definitely be some friction" in the case that the child slides a bit, under the pull of his/her weight (074).

072 **Ka** I don't think there is any friction here .. because the child is stationary .. she doesn't go down the slide .. and because of this there is no friction created ..
073 **Int** I see .. and how do you think that she manages to stay still up on the slide .. /
074 **Ka** umm .. she is grasping the sides of the slide with a lot of force .. umm .. I am not sure .. but maybe there is some friction there .. because with the weight .. which is pulling the child downwards .. she might slide a little .. and then there will definitely be some friction .. and then she has to exert some more force with her hands at the sides of the slide .. if she wants to remain still .. and not slide any further ..

*Four children (**Ba, Jn, Geo, Di**) appear to be considering that there is more friction in **B** situation because there are more points of contact for friction to be exerted, but also because the child remains motionless up on the slide.*

For example, (**Ba**) is indicating that there is more friction in ***B*** situation because there are more points of contact, since the child is touching more on the slide, but also because "he is not sliding at all" (069).

068 **Int** I see .. where do you think that there is more friction here .. / in A or in B situation .. /
069 **Ba** er .. here in B .. because it has more points of contact .. more points where the child is touching the slide .. for that .. and also because he is not sliding at all ..

In a similar way, (**Jn**) points out that there are more points of contact in the second situation, since the child "needs a lot of friction to manage" to "remain still up on the slide" (072).

071 **Int** where do you think that there is more friction here .. / in A or in B situation .. /
072 **Jn** umm .. in picture B .. because we have more points of contact .. and also because the child remains still up on the slide .. and he needs a lot of friction to manage that .. {pointing at the points of contact of the child with the slide}

*Two children (**Nt, Joh**) appear to be suggesting that there is more friction in **B** situation, because "there is one more friction" than in **A** situation.*

Thus, (**Joh**) for example is indicating that the friction at the shoes and the trousers of the child is the same in both situations, whereas the friction that is exerted by the hands of the child at the sides of the slide, is "one more friction" in ***B*** situation, since "he has to exert more friction to remain motionless" (077).

076 **Int** I see .. where do you think that there is more friction here .. / in A or in B situation .. /
077 **Joh** umm ..4.. the last two frictions are the same .. I mean .. at the trousers .. and the shoes .. but here is B situation .. he is exerting one more friction .. the third friction .. which is with his hands at the sides of the slide .. so he has to exert more friction to remain motionless .. up on the slide ..

*Two more (**Ge, Ni**) children point out that there is more friction in **B** situation, because the child has to "increase" his/her friction to remain stationary, up on the slide.*

For example (**Ni**) appears to be suggesting that since in ***B*** situation the child does not slide down "friction must be more" because the child has to "increase friction a lot more", in order to remain motionless up on the slide (069).

067 **Int** where do you think that there is more friction here .. / in A or in B situation .. /
068 **Ni** er .. here in the second case .. because it like the first .. but the child does not slide down .. so friction must be more ..
068 **Int** why do you think this happens in the second case .. /
069 **Ni** er .. because the child has to exert a lot more force with his hands .. in order not to slide downwards .. so he has to increase his friction a lot more ..

There is only one child (**Bi**), who suggests that there is more friction in ***A*** situation because the child is sliding down and "he is rubbing more", whereas in ***B*** situation the child remains motionless, and consequently "he is rubbing less", creating less friction (078). In this sense, "rubbing" appears to be her criterion of reference.

077 **Int** where do you think that there is more friction here .. / in A or in B situation .. /
078 **Bi** umm .. in A situation because he is sliding and rubbing more .. whereas in B situation the child remains motionless and so he is rubbing less .. that's what I think ..

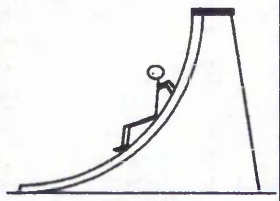
Interview Card	*Groupings of conceptions and alternative conceptions*	*NoR*
	• **There is friction exerted at the points of contact of the child and the slide, but there is more friction at the hands of the child, which are "held" or "pressed" at the sides of the slide.**	*8*
	• **The weight of the child is "helping" in the creation of friction, because it is making the child "touch" on the surface of the slide.**	*1*
	• **There might be some friction in this case, but there is "definitely some friction" when the child is sliding.**	*1*
	• **There is more friction in *B* situation, because:**	
	• **there are more points of contact**	*4*
	• **because "there is one more friction" than in *A* situation**	*2*
	• **the child has to "increase" his/her friction to remain stationary**	*2*
	• **There is more friction in *A* situation, because the child is "rubbing" more on the slide.**	*1*

Table 4.4.7: A synopsis of the groupings of conceptions and alternative conceptions from the analysis of the "person holding steady with the hands up on the slide" instance with respective numbers of children's responses (*NoR*).

Discussion

All of the children in this study appear to have developed and elaborated conceptions about friction and frictional phenomena within the framework of "surface roughness" theory (cf. § 2.2), which has been investigated and discussed during the teaching intervention (cf. § 5.2). Hence, children appear to be suggesting that friction is "created" because surfaces in contact are "rough" or "uneven" and they have "asperities", "little hills and valleys", "crannies", "projections and cavities", which "get into one another", "grip", "fix", "catch", or "get stuck" with each other. In this way, friction can hold things in their place (box on the slope, book on the tilted table, block of wood on the table), or slow things down when, for example, the crannies of the tyres are "hitting" on the "projections" or "irregularities" of the ground (bike). In this sense, the nature of the surfaces in contact plays an important role in the creation of friction. For example, some children claim that the book on the tilted table will start sliding easier if the tabletop is well-planed or made of plastic laminate.

Some children appear to be relating friction explicitly with "gripping" and "rubbing". They seem to be using these terms within a context of describing frictional phenomena that happen in the interface of two objects in contact. Thus, for example, children appear to be considering the "rubbing" that occurs along the interface of the shoes and the ground as an important element in the creation of friction. Likewise, in the *'person going down the slide'* instance some children appear to be suggesting that the "rubbing" of the person with the surface of the slide creates friction which slows down his/her sliding. On the other hand, this conception appears to have a negative effect for (**Ka**) who seems to be suggesting that there is no friction in the absence of "rubbing", or relative motion of two surfaces in contact (e.g. the box on the slope, the person holding steady with the hands on the slide, book on the tilted table). It needs to be noted that in Greek the words "rubbing" and "friction" have a common root and similar meanings and connotations (cf. § 2.1). In the context of everyday language,

both of these words mostly refer to phenomena of surfaces in contact, which are in relative motion with each other and they "rub" together. Perhaps this can be a source of confusion for (**Ka**) and other children.

In many instances, (book on the tilted table, box on the slope, block of wood on the table, the slow-down of the bicycle, or the person going down the slide) the children appear to be considering the force of weight as an assisting force to friction because it makes the contact of two surfaces possible. Thus, it "sticks" or "fixes" two surfaces together by pulling the upper surface downwards and this "helps" their "interlocking", which creates friction. This is corroborated by the fact that in many instances, children symbolise friction with an arrow pointing downwards alongside with the force of weight (cf. § 5.3).

In instances of sliding (block of wood on the table, person going down the slide) most of the children appear to be considering that there is still some friction because the surfaces are still "rubbing", or objects "don't move very fast".

Some children are indicating that friction is reduced when oil or water exists in the interface of the surfaces in contact, because it looks as if they are "loosing their roughness" and become "smooth". An interesting view is expressed by (**Geo**) who suggests that ice becomes very "smooth" and slippery due to melted water on its surface.

5.5.0. Highlighting some aspects of children's conceptual change: Two cases (Bi, Di)

In this section there is an attempt to present and discuss two cases of children on the basis of an overview and comparison between some of the conceptions they expressed in the pre-intervention interviews (**Pre-I.I.**) and those expressed in the post-intervention interviews (**Post-I.I.**). It is anticipated that this will highlight some aspects of their conceptual change, in reference to friction and/or frictional phenomena. Both of these cases of children are considered to be indicative and they have been chosen because they represent some very interesting aspects of children's conceptual change.

5.5.1. The case of (Bi)

Throughout the **Pre-I.I.**, (**Bi**) appears to be considering that the force of weight is "pressing" and "holding" things (book, car) motionless on surfaces like a tilted table or the ground. She considers that things are more easily dragged than lifted because their weight is "divided" between the ground and an exerted pulling force. She views the air as a retarding medium slowing down the descent of objects like a parachute, but she makes no such reference for the tennis ball in the respective instance. She also points out that the nature of the surface of the road might have an effect in the slowing down of the bike and the skateboard. Thus, she is ascribing a "frictional characteristic" to the surface of the road.

In the '*book on the tilted table instance*' she points out that there is a "force" exerted along the interface of the book and the table. She seems to suggest that it is "probably" the "weight" of the book, which "presses" it on the table and "holds" it there (022). Furthermore, she indicates that since the table is made of "hard material" (026), it doesn't "sink in" and in this way, it can hold the "push" of the weight of the

book (024). Thus, she appears to be ascribing a "frictional characteristic" to "weight", but she also considers an effect that the material of the surfaces in contact can have.

022	**Bi**	I think there is a force exerted over here .. because it doesn't fall .. it doesn't slide down the table .. er .. it is probably the weight of the book which presses there and holds it in that place ..	[pointing along the area of contact of the book and the table]
023	**Int**	what do you mean .. it presses there .. /	
024	**Bi**	umm .. to push downwards .. and because the table doesn't sink in .. er .. it remains in its place ..	
025	**Int**	the table doesn't sink in .. is that a force .. /	
026	**Bi**	umm .. no the material of the table .. is hard .. that's what I think ..	

Similarly, in the '*man pushing the car*' instance, she seems to be indicating that "a force" may resist the intended movement of the car (034 & 036). That force seems to be its weight, since the car is "heavy" and its weight "is holding it" on the ground (037). Moreover, the only force she appears to be recognising, at the touching points of the tyres and the ground, is the weight, which "falls" on the tyres and "holds them on the ground" (039).

034	**Bi**	er .. because it has a force that resists it ..
035	**Int**	how do you think .. that it resists .. /
036	**Bi**	er .. as the man is pushing it and .. the car does not move ..
036.5	**Int**	>> umm hmm ..
037	**Bi**	.. er .. because it has a force and it resists .. er .. it is heavy .. and it weight is holding it .. er .. it makes it difficult for the man to move the car .. because .. he is not so strong either .. he must be very strong to manage to move it on his own ..
038	**Int**	do you think there are any forces at the touching points of the tyres and the ground .. /
039	**Bi**	umm .. no .. it's only the weight of the car .. that falls on the tyres .. umm .. the same with the shoes of the man .. that where all of his weight falls and holds them on the ground ..

In the '*child dragging the chair*' instance, she is recognising the force of the child pulling the chair and the weight of the child and the chair (053 & 055). But, she also points out that it is easier for the child to drag the chair instead of lifting it up. Thus, she indicates that when the chair is dragged, its weight "is divided between the pull of the child and the ground" and this makes it easier for the child to move it (057). Hence, she appears to be considering that things are moved more easily when they are dragged instead of lifted.

056	**Int**	if the child lifts up the chair .. instead of pulling it .. to move it .. will that be easier for the child .. /
057	**Bi**	it would be easier for the child now that he is dragging it .. because he is dragging a bit of its weight .. because it is divided between the pull of the child and the ground .. and so it will be easier .. but if he lifts it up .. then he will take all of his weight .. and it will be more difficult for him ..

In the '*parachute*' instance she appears to be suggesting that the box is coming slowly down because the parachute is "pumped up" by the air and in this way, it "is retarding its downfall" (067). She describes it to be "like a brake" using a familiar instance as an analogy. Hence, she appears to be holding a conception of "air resistance", or a view that air may be a "retarding medium" for bodies that move through it.

066 **Int** I see .. how do you think that the parachute is going slowly down to the ground .. /
067 **Bi** er .. it's because with the parachute the box is coming slowly down .. that's because the air is getting inside it and .. it pumps it up .. and that is slowing it down .. it is like .. air is retarding its downfall .. like a brake .. sort of .. I can't explain it any better ..

In the '*slow-down of the bicycle*' instance, she suggests that the bike will stop moving because the child is not pedalling any longer, so there is "no more force" to keep it moving (077). She does not consider any forces at the touching points of the tyres and the ground, but she points out that if the road is "bad" or has "potholes", affecting the tyres then the motion of the bike is hindered, so it will stop faster (081). She considers this to be "something like a force" (083). Hence, she recognises that the nature of the surface of the road might have an effect on the motion of the bike.

078 **Int** do you think there are any forces at the touching points of the tyres with the ground .. /
079 **Bi** no .. I don't think so .. er ..4.. only when the road is bad .. and it has potholes
080 **Int** what will happen then .. /
081 **Bi** er .. the bike is going to stop a lot faster .. because the tyres are getting into the potholes and they are hindering its motion
082 **Int** and .. do you think it is a force .. /
083 **Bi** umm .. it is something like a force .. how can I say it .. it makes it difficult for the bike to move ..

Likewise, in the '*skateboard*' instance, she is indicating that if there are "potholes" on the road then "it will be dangerous for the child" and the bike will stop "a lot faster" (091). However, this effect of the road is not considered to be a force.

090 **Int** do you think there are any forces at the touching points of the wheels and the ground .. /
091 **Bi** no .. except if .. like the bike .. if there are potholes on the road .. then it will be dangerous for the child .. er .. and he will stop a lot faster .. but again this is not a force .. I don't know ..

Some of (**Bi**)'s preconceptions discussed above could be represented in a schematic way as follows:

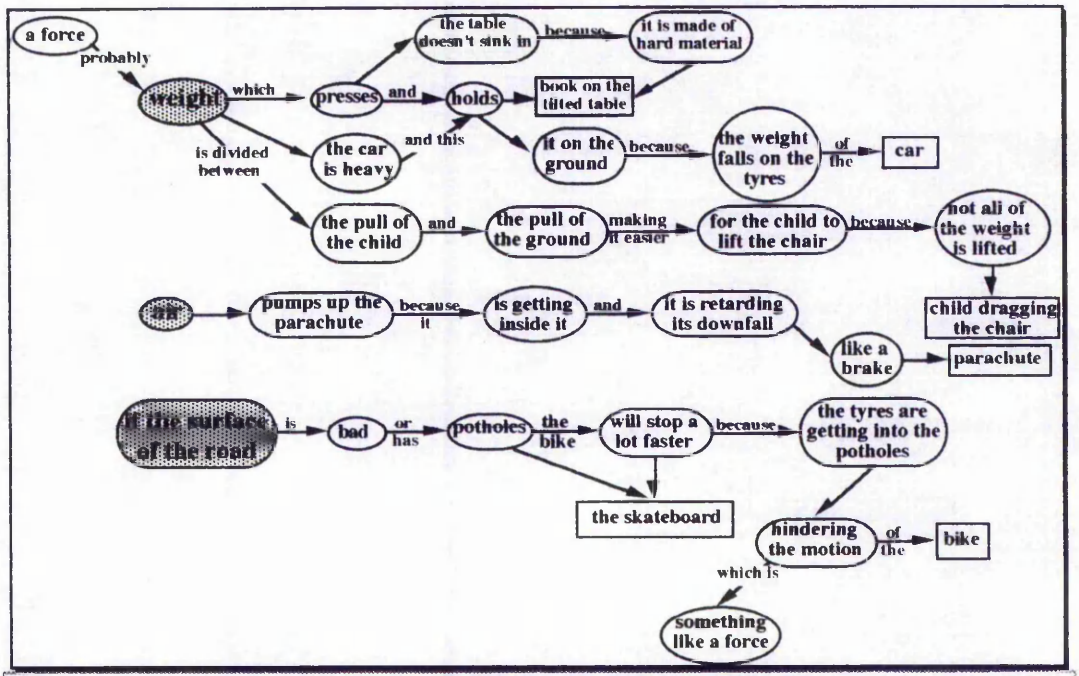


Fig. 5.5.1: A schematic representation of some of (**Bi**)'s conceptions from the **Pre-I.I.**

Throughout the **Post-I.I.**, (**Bi**) appears to be suggesting that friction depends on the "roughness" of surfaces which have "cavities and projections" and they "grip" or "interlock" with each other. In the case of the *'book on the tilted table'* she is considering a "helping role" of the weight in the creation of friction, but she does not refer to it in the *'box on the slope'* instance. She also appears to be holding a conception of friction closely related to "rubbing" surfaces and she points out that there is still "some friction" when the surfaces are in relative motion with each other (block of wood sliding on the table). Furthermore, she is the only child, from those interviewed, who in most cases symbolises friction with an arrow pointing in the opposite direction of the motion or the intended movement of bodies. Nevertheless, she is also the only child who claims that there is more friction when the person goes down the slide attributing this conception to the "rubbing" of surfaces. Hence, her conception of friction being dependent on the "rubbing" of surfaces doesn't seem to be in harmony with her conception of friction being dependent on the nature of the surfaces in contact. At least she appears to be using a different conception for different contexts.

In the '*book on the tilted table*' instance, she points out that friction "has to do" with the surfaces of the book and the table, which are "touching one over the other". Moreover, she appears to be suggesting that the book, has a "potential movement" along the surface of the tilted table, when she says that it is "about to slide down". This is attributed to the pulling force of its weight, which is "also helping it to hold on the table", because it is making it "touch with the table" (008). But, friction is also created, since the surfaces are rough and they "interlock" or "grip" (009) with each other, keeping the book stationary "in its place", up on the surface of the table.

008 **Bi** er .. friction is stopping it where it is .. it doesn't let it move .. umm .. because .. it has to do with the surfaces .. which .. are touching .. one over the other ..
007 **Int** what do you mean .. /
008 **Bi** er .. as the book is about to slide down .. because its weight is pulling it .. its weight is also helping it to hold on the table .. because it's making it touch with the table .. on the surface of the table .. and that's where friction is created .. because both of the surfaces are rough .. and it looks as if the interlock with each other ..
008.5 **Int** >> umm hmm ..
009 **Bi** .. and that's how the book remains in its place .. it's as if it grips and it stays still .. that's how I think of this ..

In the '*person walking along the street*' instance, she is considering the "rubbing" of the shoes on the ground and suggests that they are "gripping" on the surface of the ground. This happens because "there are no perfectly smooth surfaces". Instead they have "cavities and projections", which are gripping with each other, much like "the jigsaw puzzle" (022).

020 **Bi** er .. as he is walking it is like .. the shoes are rubbing on the ground .. er .. because the shoes are gripping on the ground and so he doesn't slip ..
021 **Int** can you describe .. how do you think that the shoes are gripping .. /
022 **Bi** er .. because there are no perfectly smooth surfaces .. so the shoes and the road .. are full of cavities and projections .. and as the shoes are touching the ground .. it is as if they are gripping .. just like the jigsaw puzzle .. that's how it happens ..

In a similar way. in the '*box on the slope*' instance, she is suggesting that friction is created along the interface of the box and the slope because the irregularities of the surfaces "are getting inside one another" (031). In this case though, she does not refer to the "helping role" of the "weight" of the box, as she had previously referred to it, in the '*book on the tilted table*', which is a similar instance.

027 **Bi** yes .. there is friction here .. it's the box that would probably slide down .. but friction doesn't let it slide ..
028 **Int** where do you think there is friction here ..

029 **Bi** er .. at the surface of the box that is touching the slope ..
030 **Int** why do you say that .. friction doesn't let it slide .. /
031 **Bi** er .. it is like the table and the book .. the projections of the box are getting inside the cavities of the slope .. umm .. or also the opposite .. and so friction is created ..

In the '*block of wood on the table*' instance, she points out that friction is holding the block stationary on the table, until it is pulled by a "greater weight" to start sliding (044). This happens because "there are cavities and projections" on the surfaces of the block and the table and they "grip", creating friction (046). Thus, the block remains stationary, despite the pulling force of the weight. She also points out that there will still be "some friction" when the block is sliding along the surface of the table, because it "doesn't go very fast" (050). Hence, she appears to be considering that friction is also retarding the motion of objects.

044 **Bi** yes .. friction is holding it there .. until we put a greater weight .. so the block will start sliding on the table .. as we experimented in class some days ago ..
045 **Int** yes .. I see .. how do you think that friction is keeping the block stationary .. in this case .. /
046 **Bi** er .. there are cavities and projections on the surface of the block and the table .. and when we have sandpaper .. they are even more .. er .. and they grip together .. and so friction is created .. keeping the block stationary .. despite the weight pulling it over the other side of the table ..
047 **Int** what will happen if we add some more weight .. /
048 **Bi** er .. the block will start moving on the table ..
049 **Int** do you think there is any friction when the block is moving on the table .. '
050 **Bi** yes there is still some friction .. because it doesn't go very fast on the table ..

In the '*slow-down of the bicycle*' instance, she appears to be suggesting that friction is "reducing the speed of the bike", due to the "rubbing" of the tyres on the ground. But also, the bike will stop soon, because "the child is not pedalling any more" (054). She describes this "rubbing" of the tyres with the ground "as if they are hitting the projections of the road", when they are "spinning" round, and that slows them down, decelerating the motion of the bike. She also points out that if the child uses the brakes, the bike will "stop faster", because the brakes are "grasping" the wheel, creating "a lot of friction" (058).

054 **Bi** yes .. it is reducing the speed of the bike .. because the tyres are rubbing on the road .. and the child is not pedalling any more .. or using the brakes ..
055 **Int** what do you mean when you say that the tyres are rubbing on the road .. '
056 **Bi** er .. as they spin .. they rub .. I mean .. it is as if they are hitting the projections of the road and they are slowing down bit by bit .. and gradually the bike will stop moving .. umm of course it would stop faster if he used the brakes ..
057 **Int** what would happen then ..
058 **Bi** then .. a lot of friction would be exerted from the brakes on the wheel .. as they grasp it .. and they will stop the bike faster and easier..

In the '*going down the slide*' instance, she is expressing a rather unusual conception about friction being dependent on the length of the slide. Thus, she suggests that if the slide is a "short" or "small" one, there will be more friction. This is because the child is going down "slowly", since the "appropriate time" to develop some speed is not available, due to the short length of the slide. Consequently "he rubs more" on its surface, creating more friction (064). She symbolises friction with an arrow pointing in the opposite direction of the motion of the child, that is, upwards, along the surface of the slide. She suggests that it is this way because "it is kind of stopping the child from going down fast" (068).

062	**Bi**	yes there is friction here .. but it depends on how long the slide is ..	
063	**Int**	why do you say that .. /	
064	**Bi**	er .. because if the slide is a long one .. then the child will slide down with a lot of speed and so .. there will be less friction .. because he will be rubbing less .. whereas if the slide is a small or a short one .. the child will slide slowly .. he doesn't have time to go down faster .. and so he rubs more ..	
065	**Int**	I see .. where do you think that friction exists .. /	
066	**Bi**	er .. at the points of contact of the child and the slide .. that is the shoes .. and where he is sitting ..	
067	**Int**	how would you symbolise friction with an arrow here .. /	
068	**Bi**	umm .. like this .. because it is kind of stopping the child from going down fast ..	[forming an arrow pointing upwards along the surface of the slide]

In the '*person holding steady with the hands up on the slide*' instance she seems to be considering that there is also "some friction" at the points of contact of the child with the slide. She points out though, that "the child is grasping the sides of the slide with a lot of force", creating friction there as well (074). Thus, the child "can grip up on the slide" because he/she is using "a lot of strength" in order to remain motionless up there (076).

072	**Bi**	yes .. there is also some friction here .. there .. where the child is touching on the surface of the slide ..	[pointing at the three respective points of contact]
073	**Int**	where do you mean .. /	
074	**Bi**	er .. at his shoes .. at his trousers .. here he is sitting and at his hands .. where he is grasping the sides of the slide with a lot of force ..	
075	**Int**	how do you think that there is friction at his hands .. as you say .. /	
076	**Bi**	er .. his hands .. as he is grasping the slide and .. he doesn't slide .. it is because he is exerting a lot of force .. and so he can grip up on the slide .. with a lot of strength .. so there must be some friction there that is holding him steady ..	

She is the only child that suggests that there is more friction in ***A*** situation because the child is "sliding and rubbing more", whereas in ***B*** situation the child is motionless and therefore he/she is "rubbing less", creating less friction (078). Thus, the extent of

"rubbing" appears to be her criterion in deciding in which situation there is more friction. Moreover, this is the only case that she symbolises friction with three arrows pointing downwards, at the respective points of contact of the child with the slide, because she suggests that it is "as if it is pushing the child to grip on the slide" (080).

077	**Int**	where do you think that there is more friction here .. / in A or in B situation .. /	
078	**Bi**	umm .. in A situation because he is sliding and rubbing more .. whereas in B situation the child remains motionless and so he is rubbing less .. that's what I think ..	
079	**Int**	I see .. if I asked you to symbolise friction with an arrow .. how would you symbolise it .. /	
080	**Bi**	I would symbolise it with three arrows .. one here .. and another one there and there .. pointing downwards .. because it is .. as if it is pushing the child to grip on the slide ..	[forming three arrows pointing downwards, one at the hands of the person, another at the shoes and a third one at the buttocks of the child]

In most of the other instances (*'book on the tilted table'*, *'person walking along the street'*, *'box on the slope'*, and *'the child going down the slide'*) she symbolises friction with an arrow that points in the opposite direction of the movement or of the intended motion of bodies (cf. § 5.4).

Some of (**Bi**)'s conceptions of friction and relative phenomena could be represented in a schematic way as follows:

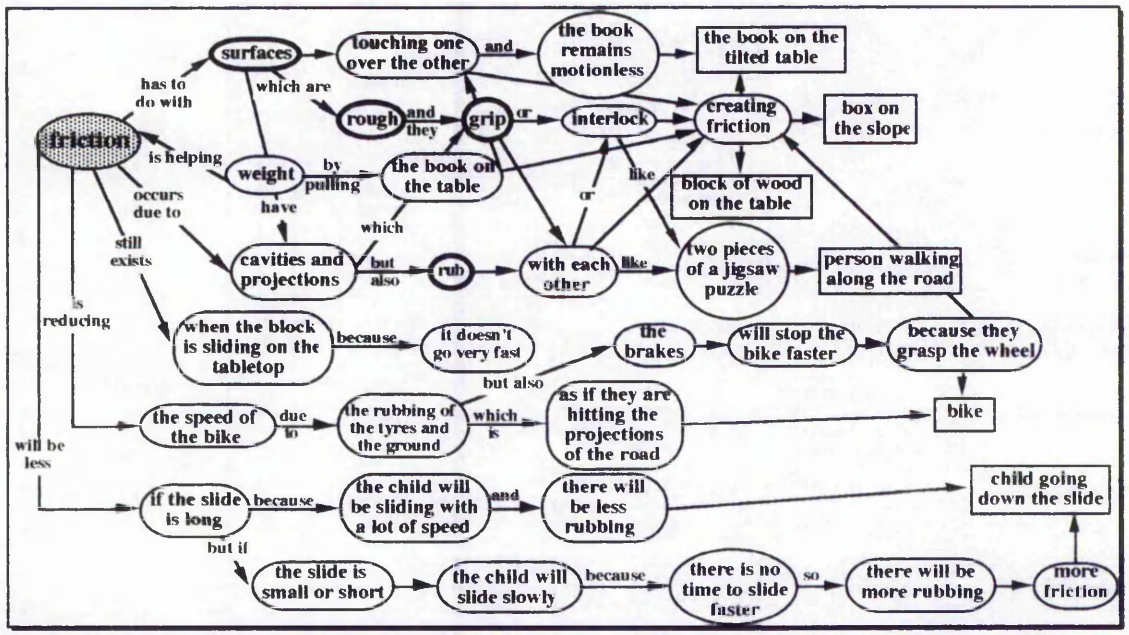


Fig. 5.5.2: A schematic representation of some of (**Bi**)'s conceptions from the **Post-I.I.**

On the whole (**Bi**) appears to have retained her initial conception about "weight" being responsible for the motionless condition of objects, but now, she also appears to

consider friction as a force that has such effects. Nevertheless, she still attributes a "helping role" to weight in bringing the surfaces to contact and create the necessary condition for friction to occur. Her preconception that the nature of the surface may affect the slow down of the bike and the skateboard appears to have developed to a surface dependent notion of friction which is basically related with characteristics of "roughness" and "grip". Friction is also closely related to the rubbing of surfaces, which appears to be a conception mostly used in contexts where a surface is sliding over another (e.g. person going down the slide).

5.5.2. The case of (Di)

Throughout the **Pre-I.I.,** (**Di**) appears to be considering several issues that are related to friction and frictional phenomena. Thus, he appears to be sensing "something" or maybe a "force" that holds the book steady on the tilted table. Then, he suggests that it could be the nature of the material of the surfaces in contact. The "earth" seems to be retarding the motion of the bike, or the skateboard, because it has a "rough surface" with "stones or potholes". Thus a "frictional characteristic" is ascribed to "earth", or the nature of the surface of the ground. Furthermore, the "weight" appears to be "helping" the slow-down of the skateboard because it is "pressing" the wheels, but it also seems to be "holding" the children on the ground. He is also using a conception of "action" and "reaction", where the latter is mainly associated to movement, but it is not ascribed any "frictional characteristic".

In the *'book on the tilted table'* instance he appears to be sensing a "force" (018), or "something" that "must be holding" the book on the tilted table (022). Thus, he points out that "it" is probably related with the table, or better, the nature of the material that it is "made of". Hence, the book would "somehow grip" on a wooden table, whereas it would slide on a table covered with plastic laminate, even if the table is not lifted higher (026).

018	**Di**	yes there is a force ..	
019	**Int**	what do you mean .. /	
020	**Di**	because for the book to fall .. there must be .. er .. we must lift it a bit higher ..	
021	**Int**	umm hmm .. why do you think that we have to do that .. /	
022	**Di**	because .. even here .. it cannot slide down .. because something must be holding it ..	[pointing at the card]
023	**Int**	what do you think that it is .. /	
024	**Di**	er .. the table ..	
025	**Int**	how do you think that the table holds the book steady in its place .. /	
026	**Di**	er .. it depends from what it is made of .. er .. from wood .. if the table was wooden then .. somehow .. the book grips on it .. and holds up there .. but if it has plastic laminate on here then it may even slide .. even if we don't lift it very much ..	[pointing at the surface of the table]

In the '*man pushing the car*' instance the only "forces" that he appears to be considering, at the touching points of the tyres of the car and the shoes of the person with the ground, are the weight as an "action" and "a reaction exerted by the earth" (040). He does not refer to any surface effect though.

039	**Int**	do you think there are any forces at the touching points of the tyres with the ground .. /	
040	**Di**	yes .. because there at the tyres .. and at the shoes of the person .. an action is exerted .. er .. from the weight .. and a reaction is exerted from the earth ..	[pointing at the tyres and the shoes]

In the '*children playing with the tennis ball*' instance he suggests that the weight of the children is keeping or "holding" them on the ground and they don't "slip" (052 & 054). The shoes also appear to have some role here, but it is not discussed further. Thus, he seems to be ascribing a "frictional characteristic" to weight.

052	**Di**	er .. the children with their shoes .. umm .. their legs .. let's say .. that is with their weight .. they cannot go away ..
053	**Int**	what do you mean .. /
054	**Di**	the child with his legs .. I mean with the shoes that he is wearing and he doesn't slip .. and the earth that is holding him with the weight that he has ..

In the '*child dragging the chair*' instance he is indicating that there is an "action" from the child who is "walking", and from the legs of the chair on the ground. He suggests that the earth is exerting a "reaction" (066) which appears to be closely related to movement (068). He seems to be considering that the chair is moved easier when it is dragged because "the earth is exerting a reaction force to its weight" and that is a "help" for the child (070).

066	**Di**	well .. with his legs there is an action .. and the earth has a reaction .. because here he is walking .. er .. also the child has a force with his hand .. he is pulling the chair .. but also the chair has an action on its leg and the earth has a reaction .. because it is also moving ..
067	**Int**	where the child is pulling the chair ... what force do you think there is .. /
068	**Di**	umm .. it's the action because .. it is helping it to move ..

069 **Int** I see .. when do you think that the child is exerting more force .. now that she is dragging it .. or when she is lifting it up .. to move it .. /

070 **Di** er .. now that she is dragging it .. because when she is lifting it up .. she is lifting all of its weight .. so she will have to exert a greater force .. whereas now .. the earth is exerting a reaction force to its weight *(chair)* and that helps the child ..

In the '*parachute*' instance he suggests that air is getting inside the parachute and "it is as if it is pushing it upwards", "holding" it in the air. This seems to be retarding the downfall of the parachute. Thus, he appears to be considering a notion of "air resistance" for bodies that move through it.

078 **Di** er .. as it falls downwards .. the air is getting inside the parachute .. and it is as if it is pushing it upwards .. and it is holding it in the air .. and so it goes slowly towards the ground .. er .. it holds the air inside it and it doesn't fall quickly .. with great force ..

In the '*slow-down of the bicycle*' instance he points out that apart from the fact that the child has stopped pedalling, it is also the earth that "does not let the bike move freely" (092). This is because the tyres are "rubbing" on the ground and this appears to be hindering the motion of the bike (094). He does not consider that to be a force though, but he seems to be indicating that it is common experience for him, since he suggests that the bike will stop faster if the road has "stones or potholes" (096). Hence, he is ascribing "frictional characteristics" to the "rubbing" tyres and to the nature of the surface of the ground.

091 **Int** I see .. in this case the bike goes slowly and sometime it is going to stop .. why do you think that happens .. /

092 **Di** because the child stops pedalling and .. since he is not using the brakes .. then the bike will stop slowly on its own .. but also because the earth does not let it move freely ..

093 **Int** what do you mean .. the earth does not let it move freely .. /

094 **Di** er .. it is because the tyres of the bike are rubbing on the ground .. and it won't go any further .. it might run into a stone and stop suddenly .. or it might even fall down ..

095 **Int** I see .. do you think this has to do with any force .. /

096 **Di** umm .. no .. it looks like this to me .. and if the road has stones or potholes .. then it will stop a lot faster ..

In the '*skateboard*' instance he seems to be considering the absence of an exerted force by the child as a reason for its deceleration. Furthermore, he points out that the weight of the child is "pressing" the skateboard and then the ground (103) and if the child is heavy then the skateboard "might stop faster" (105). He appears to be suggesting though, that the earth is somehow hindering the motion of the skateboard

(107). But, he seems to be viewing that in relation to the weight of the child, which is "pressing" on the wheels (109).

103	**Di**	er .. because the skateboard doesn't have any force .. it can't keep going .. and because the child is not pushing any longer with his leg .. er .. it is going to stop in a while .. and because the child with his weight of the child is pressing the skateboard and that is pressing the ground ..
104	**Int**	I see .. what do you mean when you say .. it is pressing the ground .. /
105	**Di**	it is pushing it downwards .. and if the child is heavy .. er .. then it might stop faster ..
106	**Int**	anything else you want to add here .. /
107	**Di**	yes .. for the skateboard to move on the child has to exert a force with his leg .. all the time .. otherwise the earth does not let it move .. /
108	**Int**	what do you mean .. the earth does not let it move .. /
109	**Di**	er .. with the weight of the child .. it is pressing the wheels .. and it will stop .. it can't happen in another way ..

Some of (**Di**)'s preconceptions analysed above could be presented in a schematic way as follows:

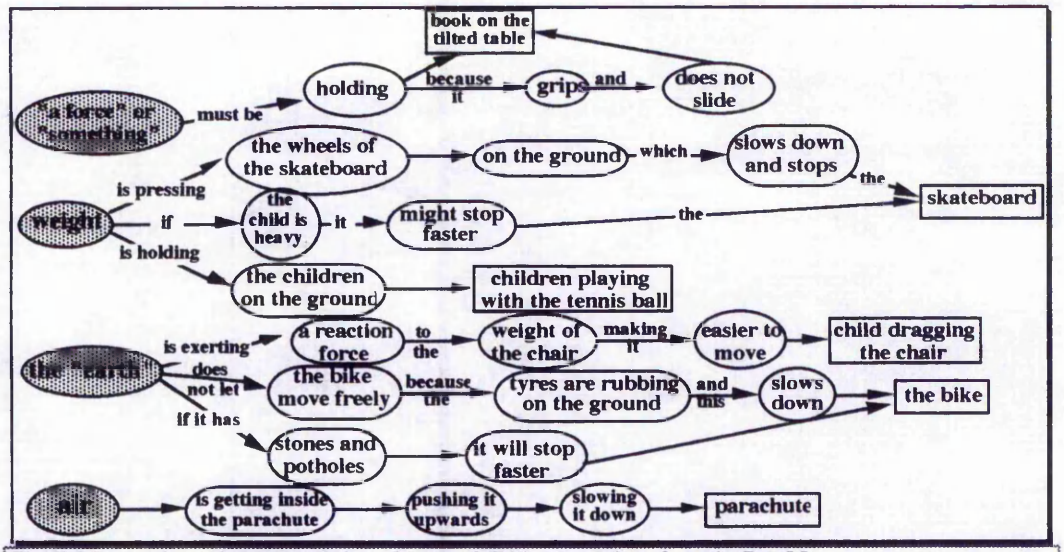


Fig. 5.5.3: A schematic representation of some of (**Di**)'s conceptions from the **Pre-I.I.**

In the **Post-I.I., (Di)** appears to have maintained his conception about the frictional properties of the nature of the surfaces in contact, together with a "helping role" ascribed to "weight" for the creation of friction. He considers that friction is created because the surfaces are "rough" or "not smooth" and the "cavities and projections" of one are getting into the other, or they "interlock", "catch" and "grip" with each other, just like two pieces of a "jigsaw puzzle". He seems to be suggesting that without the existence of friction, the person wouldn't be able to walk on the street, or the cars

wouldn't be able to move on the surface of the ground. He also points out that friction is retarding the motion of objects or it "is holding them back", slowing them down, or preventing their movement.

In the '*book on the tilted table*' instance he suggests that friction depends on the nature of the material of the surfaces in contact (006 & 007). Thus, the table "must be wooden" since the book does not slide down, and this is because the book is touching on the table (009). Also, its weight is pulling it downwards onto the table and in this way it seems to be creating the necessary conditions for friction to be exerted along the interface of the book and the table. This is because the surfaces are "not smooth" and they have "hills and valleys" that "get into one another" (011). Thus, he appears to have kept his conception of the "helping" role of weight in the creation of friction. He also points out that the book would slide down easier on plastic laminate because it "is smoother than wood" (013).

006	**Di**	.. it depends on what the book is made of .. /
006.5	**Int**	>> umm hmm ..
007	**Di**	.. on whether the book is smooth .. or .. whether it is rough .. and this is also same for the wood .. of the table .. it also has to do with the surfaces
008	**Int**	and what happens here .. / can you describe it .. /
009	**Di**	er .. because if the table is wooden .. and it must be wooden here .. since the book does not move .. umm .. the book cannot move and the table needs to be lifted higher ..
010	**Int**	what happens between the surfaces then .. /
011	**Di**	er.. the book is touching on the table .. but its weight is pulling it downwards .. and so the wood of the table is hindering its motion .. because it is not smooth .. it has little hills and valleys .. which get together .. and it is as if they interlock with each other .. and so friction is created ..
012	**Int**	and what if the table was not wooden .. but it had plastic laminate like this one .. / what would happen then .. /
013	**Di**	er .. there would be a grater chance to slide down .. because the plastic laminate is smoother than wood .. but it also depends on how high the table is lifted .. because if we lift the table higher .. then the book will start sliding ..

In the '*person walking along the street*' instance, he appears to be describing how the person manages to walk and he points out that the ground is pushed with the person's shoes or better "the earth is pushed backwards". Then the rough surfaces of the shoes are "gripping" or "catching" with the "projections and the cavities" of the ground interchangeably, like two pieces of a jigsaw puzzle (024). He points out that "we can walk" because friction is created along the interface of the shoes and the ground

(024), otherwise "we would slip and fall". Similarly, a road that has oil spread on it surface its surface becomes "more smooth" and slippery (026).

021	**Di**	er .. in the way the person is walking he is pushing the ground .. with his shoes .. so he can move .. pushing the ground .. /
022	**Int**	can you explain that a bit .. /
023	**Di**	er .. he is lifting his feet up and then he is touching them back on the ground .. pushing the earth backwards .. and this is because his shoes are touching the ground .. which is rough and not smooth at all .. er .. same with the shoes ..
023.5	**Int**	>> umm hmm ..
024	**Di**	er .. it is as if the shoes are gripping .. as if they are catching with their roughness .. because the projections of one are getting into the cavities of the other .. and the opposite .. just like the jigsaw puzzle .. we saw when we did those experiments on friction .. and that's how friction is created .. and we can walk .. otherwise we wouldn't be able .. we would slip and fall .. just like when there is oil on the road ..
025	**Int**	what happens when there is oil on the road .. /
026	**Di**	umm .. then it is like .. it becomes more smooth .. and so friction becomes less .. and we slip ..

In the '*box on the slope*' instance he is considering four places where friction exists, that is, at the tyres of the truck, along the interface of the box and the slope and at the two edges of the slope touching at the back door and the ground respectively (034). Again this is because the surfaces are "rough" (036) and the "projections and cavities" of one are getting into the other, so friction is "exerted", keeping the box "steady" up on the slope (037). Similarly, he is considering that the slope is "gripping" at its edges which are touching the back door and the ground, but also its weight and the weight of the box appear to be helping this "grip" once more (039). He also seems to be suggesting that the truck will be "able" to move because its tyres will be gripping on the road (039).

036	**Di**	er .. here the surfaces are rough .. the surface of the box .. if its made of paper or wood .. but also the surface of the slope .. which is made of wood ..
036.5	**Int**	>> umm hmm ..
037	**Di**	.. and the projections and the cavities of one are getting into the projections and the cavities of the other .. just like the book on the tilted table .. and so their surfaces grip .. and there is friction exerted .. which keeps the box steady in its place ..
038	**Int**	I see .. and at the points of contact of the slope with the back door of the truck .. that you mentioned .. what happens there .. /
039	**Di**	er .. there is friction again .. again it is as if the board is gripping on the back door of the truck .. and with its weight and the weight of the box .. it manages to hold at the edge of the back door .. and not fall down .. er .. also when the truck starts moving .. it will also have some friction on its tyres .. because they will be gripping on the ground .. in order to enable the truck to move ..

In the '*block on the table*' instance he is indicating that the movement of the block depends on the weight that is hung at the end of the string. Thus, if "one fourth" of the weight of the block is hung, the block will start sliding. In the case that the table

is not smooth, or it is covered with sandpaper, more weights needs to be hung, "over half of the weight of the block" (047). He is considering though, that friction will still be there, when the block is sliding on the table, because it appears to be "a bit difficult" for it to slide and it looks "as if friction is holding it back" (049).

045 **Di** well .. if the block moves here or not .. it depends on the weight we have hung .. just like what we did in class .. we weighed the block and then we hung some weights .. and we found out that the block needs .. about one fourth of its weight to start sliding ..
045.5 **Int** >> umm hmm ..
047 **Di** er .. it depends if the table is smooth or rough .. I mean .. whether it is made of wood .. or whether we have covered it with sandpaper .. then it will have a lot more friction .. and we will have to hang more weights .. over half of the weight of the block to start sliding ..
048 **Int** in the case that we have hung some weight and the block doesn't slide .. do you think there is friction there .. /
049 **Di** umm .. yes .. there is friction .. and so it will be a bit difficult for the block to slide .. because it is as if friction is holding it back ..

In the '*slow-down of the bike*' instance, it seems to him that the tyres have some difficulty "to roll on the ground" because they "rub" and that is decelerating the bike. This happens because the tyres have "rough" surfaces with "crannies" and "little valleys" and it looks as if "they hit" the "projections of the road", or they fall into "its potholes" and if the potholes are "big", the bike will stop faster (056).

054 **Di** but because the tyres as they spin .. they rub on the ground .. I mean it looks as if it is a bit difficult for them to roll on the ground .. and that's why the bike will gradually loose its speed and some time it will stop ..
055 **Int** do you think there is friction at the tyres .. /
056 **Di** er .. since the tyres have a rough surface .. they have crannies and little valleys .. and as they roll on the ground it is as if they hit on the projections of the road .. or as if they fall into its little potholes .. and if the road has bigger potholes then the bike will stop faster ..

In the '*person going down the slide*' instance he is indicating that "children" are not going down the slide with a "great speed". This is because, despite the outlook smoothness of the surface of the slides, they are always "rough" (064.5). Hence, the children are "rubbing" on them at the respective points of contact and friction is created (063 & 064.5).

063 **Di** yes there is friction in this case .. at the points of contact of the child with the slide .. I mean the shoes and the trousers ..
064 **Int** I see .. and ..
064.5 **Di** >> ah .. no matter how smooth the slides are made for the children .. to slide easily .. they always have .. they are always rough .. and so as the children are sliding .. they are always rubbing .. and that's why they don't slide down with a great speed ..

In the '*person holding steady with the hands up on the slide*' instance, he points out that the child is "as if he is sticking his hands on the slide" and so a lot of friction is exerted at the points of contact (070). This is because "he is pressing with his palms at the sides of the slide", which means that "friction is happening at his palms". This resembles to a "sucker" and it "helps" the child to remain motionless up on the slide (072). Hence, he is also using an analogy to describe friction in this case.

070 **Di** er .. yes there is friction here .. because apart from the shoes and the trousers .. the child .. it is as if he is sticking his hands on the slide .. and so he is exerting a lot of friction ..
071 **Int** what is happening with his hands .. /
072 **Di** er .. he is holding tight .. and as he is pressing with his hands .. er .. with his palms at the sides of the slide .. it is as if he is sticking .. his hands .. like a sucker on the slide .. and this helps him stay there .. that means that friction is happening at his palms .. something like this .. I cannot find a better way to describe it ..

In all of the cases that he was asked to symbolise friction, he formed an arrow pointing downwards alongside the direction of the arrow of weight (cf. § 5.4). Thus, for example, in '*the person walking along the street*' instance he suggests that friction can be symbolised with two arrows pointing downwards, one under each shoe respectively. This is because "friction is helping the child touch the ground and walk", as weight, in a similar way, helps the child "to be on the ground", due to the pulling force of gravity (028). Hence, in this context, he appears to be holding a conception of friction closely related to weight, with slightly different characteristics and/or effects.

027 **Int** I see .. if I asked you to symbolise friction with an arrow .. how would you symbolise it here .. /
028 **Di** er .. like this and like that .. with two arrows .. here at the shoes of the person .. because it is as if friction is helping the child touch the ground and walk .. just like the weight of the child helps him to be on the ground .. because gravity is pulling him downwards [forming two arrows pointing downwards]

Some of (**Di**)'s conceptions of friction and relative phenomena could be represented in a schematic way as follows:

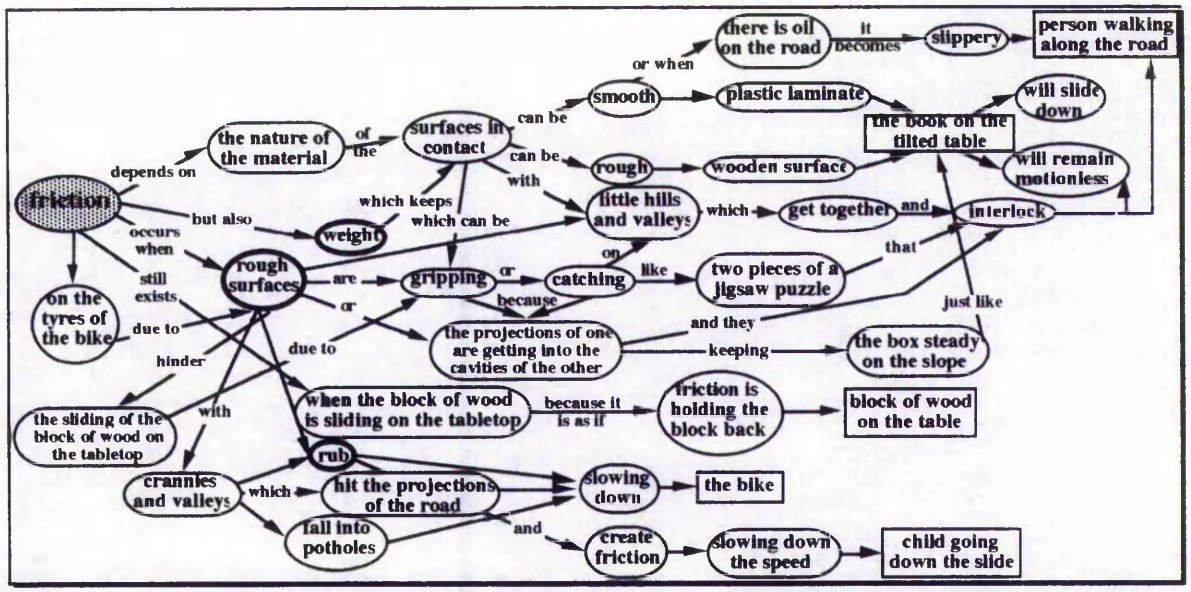


Fig. 5.5.4: A schematic representation of some of (**Di**)'s conceptions from the **Post-I.I.**

On the whole (**Di**) appears to have maintained his preconception of "weight" as a reason for the motionless condition of objects in certain instances, due to its "holding" or "pressing" effects on the surfaces in contact (e.g. book on the tilted table). Furthermore, in the **Post-I.I.,** he seems to have associated this conception of weight with friction by considering it as a necessary condition for the contact of surfaces. In this sense the weight of objects appears to be an aid to friction. She seems to have developed a surface dependent conception of friction extending a similar conception he had in the **Pre-I.I.** about the nature of the surface of the road which may affect the slow down of the bike and the skateboard. He also appears to have developed a conception of friction closely related to "gripping" and "rubbing" of the interlocking irregularities of surfaces in contact.

CHAPTER 6

Findings, Conclusions & Comments

6.0. Introduction

In this final chapter there is an attempt to discuss the findings, to reflect on some issues that concern the research methods and to express some considerations and limitations of substance and scope of this research project. The chapter is concluded with a self-critique and some implications for future research.

6.1.1. An overview of conceptual change with reference to the concept of frictional force

As it has been argued in Chapter 1 (cf. §§ 1.2.1, 1.2.2.), conceptual change is seen as a change in children's conceptions from spontaneous and intuitive to more elaborated and advanced. The overall framework of this inquiry does not orient itself towards a radical form of conceptual change or a strong restructuring of children's conceptions focusing on radical shifts and replacement of "misconceptions" or "preconceptions" with "correct" scientific conceptions. In my opinion, such major changes in the way of seeing and interpreting the world may occur rather rarely and reflect broader frameworks of conceptions that act as explanatory systems. In this sense, a shift from Newtonian physics to Einstein's relativity may represent a radical form of conceptual change which affects not only the "peripheral" conceptions but also the "hard core" of an interpretative framework (cf. Lakatos, 1970). Nevertheless, such a form of conceptual change does not appear to be the case for primary science education, where basic concepts of physics are approached by young children.

Within the context of this inquiry, a notion of a "weak form" of conceptual change or restructuring of children's conceptions is adopted. Thus, moving from a primitive to a more sophisticated conception about a certain phenomenon is not considered to be a radical shift, but "a gradual and piecemeal affair" (cf. Watts & Bentley, 1987). In this sense, children appear to be collecting and testing new pieces of information and knowledge in relation to what they already know, or what already exists within their

"conceptual ecologies". A change in the way they construe the world appears to be a change in the way of viewing things from a different standpoint, which is considered to be more plausible and persuasive. Prior knowledge and experience appear to play an important role in the process of conceptual change. Children are strongly encouraged to express and discuss their preconceptions in order to become aware of them and to receive social feedback from other children and the teacher in a class. Teaching interventions seem to be promoting conceptual change by organising and discussing investigative activities which put children's alternative conceptions to test, or provide counterintuitive and unexpected experiences. This aims to challenge children's preconceptions and often create conceptual conflict, which may be resolved through further discussion and testing, or by presenting alternative explanatory schemes such as analogies, metaphors or models. The latter need to be linked explicitly with conceptions or representations that already exist in learner's minds in order to be effective in the bridging of preconceptions with new ideas and/or pieces of information (cf. § 1.3.2). Hence, children may be persuaded to adopt a new conception and use it within a particular context, but this does not necessarily mean that at the same time they will abandon all of their preconceptions, or that they will use the new conception in all similar or differentiated contexts. Quite often children seem to reconcile older conceptions with new ones by extending some of their characteristics, or they incorporate them in new explanatory frameworks by enriching them with new properties. It appears to take time for new conceptions to become part of the conceptual ecology of a child and have a more generalised usage. It may often be the case that a new conception needs to be reconsidered and reconstructed several times within different situations and for an extended period of time, in an evolutionary rather than a revolutionary mode.

At this point, it needs to be noted further, that most of the theoretical perspectives and/or models of "strong" or "radical" forms of conceptual change (for example Posner et al., 1982; Strike & Posner, 1992), which have been discussed in chapter 1 (cf. § 1.2.1) are mainly emphasising on major conceptual shifts, which appear to be

more applicable to secondary or even University science education. Thus, they appear to make no necessary distinction for primary science education, which has several peculiarities in the teaching and learning of certain concepts and phenomena to young children. Moreover, it could be claimed that if one attempts to apply these models to teaching practice they turn out to be difficult to follow, or perhaps they tend to be more messy rather than useful. This seems to happen because they are basically learning models, which deal with a theoretical interpretation of learners' attempts to construe the world, through a logical (mostly from the standpoint of the curricularist) or rationalistic (mostly from the standpoint of the researcher) sequence of phases and/or aspects of conceptual change. Hence, if a "weak form" of conceptual change is to be adopted for primary science education, then perhaps a more "loose approach" towards a learning model needs to be considered, whereas its projections and/or links with teaching practice need to be further researched.

6.1.2. A discussion of findings

In the two indicative cases of children, which have been examined in each of the studies in England and in Greece, some aspects of a "weak form" of conceptual change have been identified and presented. An overview and a discussion of some findings is attempted here.

In the **Pre-I.I.** there appears to be a conception that "gravity" (mostly for the study in England) or the "force of weight" (mostly for the study in Greece) is considered to be a reason for holding things motionless in their place, or for retarding the motion of objects (cf. the cases of **Da, Bi, Di**). In this way, it is claimed that children seem to attribute to gravity (or the force of weight) some "frictional characteristics", in order to explain and interpret relative phenomena (e.g. the motionless book on the surface of a tilted table or the slow-down of the bike). Hence, they appear to use conceptions that they feel more comfortable with, when they attempt to explain these phenomena, or at least they have preferred to use a more familiar and well established

nomenclature to express their ideas. Nevertheless, this conception of weight or gravity, being attributed frictional characteristics, appears to be still present in the **Post-I.I.**, where children seem to ascribe a "helping role" to it, in the creation of the force of friction. Thus, things are "stuck" on surfaces due to the force of weight which is "pressing" one surface onto the other, helping friction in a way. They appear to be suggesting that gravity creates the necessary condition for two surfaces to get in contact and for friction to occur in the interface. This is quite true, because friction is created due to surfaces that come into contact in one way or another. Moreover, they appear to have found a way to reconcile their preconception of the role of gravity or weight in the description and explanation of frictional phenomena, within the surface roughness approximation of friction, which has been acquired after the teaching interventions.

In the **Pre-I.I.,** children appear to be considering an intuitive conception of "grip" (**Jo**), which can be closely related to the nature of surfaces in contact (**Da, Bi, Di**) and can hold things stationary, retard their motion, or even hinder their potential movement. These frictional properties ascribed to "grip", or the nature of surfaces in contact, appear to constitute a set of conceptions which have been retained and enhanced in the **Post-I.I.**. The use of the analogy of the jigsaw puzzle with the consequent description of the interlocking of the "roughness", or of the "projections and cavities" of the surfaces in contact, appears to have played an important role in modelling interpretations about frictional phenomena. Thus, children appear to express more accurate descriptions and more fruitful explanations in the **Post-I.I.** using conceptions of "gripping", "rubbing" or "interlocking" of surfaces in contact as intrinsic characteristics of friction. Moreover, they appear to have retained their earlier conceptions of "grip" as an observed phenomenon, or the property of rough surfaces, which may keep things stationary or slow down objects, incorporating new characteristics to it. Nevertheless, it could be claimed that there are several anthropomorphic elements within the meanings of words like "grip", "catch" and "grasp", which are often used in the interviews. This seems to be strongly related

with the everyday experience of using hands to hold things tight and move them with control. Hence, this appears to generate anthropomorphic conceptions of frictional phenomena, which refer either explicitly or implicitly to this notion of "grip having to do with human activities", which is often expressed in the interviews.

Throughout the **Pre-I.I.** children have used words like "gripping" and "catching" (for the study in England) or "rubbing" (mostly for the study in Greece) to explain some frictional phenomena. These words appear to refer to surface effects possibly coming out of everyday observation and language, but they are not considered to have a "pushing" or "pulling" characteristic of a force. Hence, they appear to be "natural" (cf. Watts & Taber, 1996) properties of surfaces which appear to have various frictional effects, or at least they are used to explain relevant phenomena. In the **Post-I.I.**, words like "gripping", "catching" and "rubbing" are still used, but they seem to be synonymous to a certain extent, or closely related to the word "friction". Hence, children seem to have enriched the meanings of such words and extended their connotations and/or their frame of reference. Moreover, in the **Post-I.I.** "friction" appears to have obtained a "pushing" or "pulling" characteristic of a force and it is not merely considered to be a "natural" property of surfaces in contact. The task of explanation of relevant phenomena appears to have moved to the use of a conception of friction with the interlocking of the roughness of surfaces and the relative teaching analogy of the jigsaw puzzle, as a common point of reference. Only (**Jo**) seems to hold a differentiated conception of "grip" and "friction", with the first referring to frictional phenomena of static situations, whereas the latter refers to sliding situations with surfaces in relative motion to each other (cf. § 4.5.1). Hence, she appears to be thinking of friction in terms of "rubbing" surfaces, but at the same time she has extended her preconception of "grip" to enclose relevant frictional effects of static situations.

6.1.3. A discussion about how language may affect the construction of meanings

If conceptual change is considered to be a "change in the way of seeing something" (Marton, 1990), meaning a change in the way of construing it and constructing conceptions about it, then language appears to play an important role in this human endeavour. The ways words are used in language and the meanings that are ascribed to them, within various contexts, appear to constitute our conceptions and "conceptual ecologies". On the meaning of words Wittgenstein (1953) writes:

> For a large class of cases -though not for all- in which we employ the word meaning it can be defined as thus: the meaning of a word is its use in the language (p. 20).

Hence, children appear to ascribe certain friction-related meanings to words like "gripping", "grasping" ,"holding", "catching", "hindering" and "rubbing", which in their turn have various meanings within their use in different situations and contexts. Conceptions that emerge from the interrelations of these meanings attempt to work as explanatory schemes or systems, which allow children to view the world, or various phenomena, in one way or another. As Sutton (1992) points out:

> Words steer perception both positively and negatively, and also they influence what people do or do not do as well as what they see or miss seeing (p. 40)

In this sense, Sutton (1992) claims that "learning science involves learning to see in new ways" (p. 41). Hence, seeing friction as a force that keeps objects stationary, decelerates the motion of objects, or even hinders the potential movement of bodies, is quite different from seeing friction as a plain surface effect, without being able to describe it, or identify some of its characteristics. Moreover, seeing friction as a phenomenon that happens in the interface of two surfaces in contact, or as an effect of the interlocking of surface irregularities is quite different from seeing frictional phenomena merely occurring as a result of gravity or the force of weight that "holds" surfaces together. Being able to understand that this is part of the phenomenon of friction, or that it creates a necessary condition for friction to occur in the interface of

two surfaces in contact, appears to be a differentiated conception from that which considers the force of weight to be the main reason for causing frictional effects.

On the other hand, it needs to be noted that the nature of the language itself appears to affect the creation of meanings in words and their connotations, within the context of their everyday use (cf. § 2.1). Thus, in Greek the word "friction" [τριβή] seems to be more closely related to the English notion of "rub" or "rubbing" [τρίβω, τρίψιμο], which is considered to be a frequent word in the everyday language of Greek children. Moreover, the Greek word "τριβή" refers both to "friction" and "rub" or "rubbing" and has implicit connotations about surfaces being in relevant motion with each other and related frictional effects. Thus, Greek children appear to feel more comfortable in using the word "τριβή" to describe and explain frictional phenomena within a familiar context of the common use of the word. This does not necessarily mean that it is easier for them to ascribe to it a differentiated meaning within the context of physics. This is probably a reason that words like "catching", "gripping", "grasping" or "slipping" are used simultaneously with the word "τριβή" in children's explanatory propositions that refer to frictional phenomena, even after the teaching intervention (cf. §§ 5.4, 5.5). In English the word "friction" appears to be a less frequent word in everyday language of children and perhaps it is closer to a technical term, at least within the context of physics. English children appear to be using words like "gripping", "catching" or "rubbing" to describe their conceptions of friction and relevant phenomena, but not in parallel with the word "friction" itself, perhaps due to its differentiated denotation as a word. Hence, the word "friction" appears to be often used as a concluding point of a propositional statement (e.g. "friction is when two surfaces rub together", or "the gripping of surfaces causes friction"), whereas other words are used to analyse its meaning (cf. §§ 4.4, 4.5). This is not often the case in Greek where the same word [τριβή] can be used as a verb and noun [τρίβω, τρίψιμο] interchangeably and create similar explanatory propositions without the use of other "supplementary" words. Nevertheless, Greek children appear to have similar

difficulties to those of English children, in ascribing "scientific" meanings to the word "τριβή", which appears to come more "natural" in their everyday language.

On the whole, it could be argued that the choice to do research in two different countries was seen more of a challenge to investigate how children think in different cultural, linguistic and/or educational contexts, instead of a methodological problem, although progressively it developed several difficulties in the conduct and report of the inquiry. As it has been argued in Chapter 1 (cf. § 1.2.1), despite the cultural differences, there is a finite set of qualitatively different ways in which a particular phenomenon is experienced, conceptualised, or understood (Marton, 1990). It appears that social and physical constraints limit the number of ways in which individuals construct their conceptions. In this sense, several similarities have been identified not only in the ways children from different countries conceptualise and explain particular phenomena, but also in the way their ideas develop or change (see for example Shipstone *et al.*, 1988). This inquiry appears to reinforce the above claim, since it can be argued that both English and Greek children involved in this project appear to construct similar conceptions about friction and to explain frictional phenomena in similar ways. Moreover, they appear to have similar difficulties in understanding and linking new conceptions with what they already know, or in ascribing new meanings to conceptions that already exist in their minds.

6.2. Some findings and suggestions from the teaching interventions in England and in Greece with relative comments

There has been an attempt to conduct the teaching interventions both in England and in Greece within a framework of a constructivist view of teaching and learning in a non-threatening environment that encourages investigative work and negotiation of meanings amongst the learners and the teacher. As Watts (1994) contends:

> So *good* constructivist practice in classrooms ought to be different to good classroom practice generally in distinct ways. The emphasis will be on active learners constructing and reconstructing their own ideas, taking responsibility for their learning in ways they know they can do, being self-determining within a caring

> group, negotiating with others towards purposive ends (pp. 52-53, emphasis in the original).

There are many similarities in the teaching interventions that were conducted in the two countries. This is despite the fact that the teaching intervention in England was conducted in three sessions, whereas in Greece the teaching intervention was conducted in two sessions. Some of these similarities can be summarised as follows:

- The instance with the book on the tilted table was used in the beginning of both of the teaching interventions to elicit some of children's initial conceptions or preconceptions of friction and related phenomena. A poll was also conducted to make these conceptions explicit and representative amongst the members of the class. Some additional instances were also used for the same purpose in both studies.

- Experiments using blocks of wood which were slid on various surfaces of tabletops were organised, conducted and discussed in both studies. These experiments resemble to the ones conducted by Leonardo, Amontons, or even Coulomb in various moments of the history of science (cf. § 2.2). Similar experimental arrangements for primary science investigations on friction have been proposed by several authors like Jarvis (1991, p. 171-173) and Wenham (1995, pp. 189-193).

- A teaching analogy with two fragments of a jigsaw puzzle and two relevant drawings was presented and discussed in order to help children understand the interlocking of the roughness or of the irregularities of surfaces and the creation of friction.

- Some implications of friction and frictional phenomena related to everyday life were discussed at the end of the teaching interventions.

- A drawing and writing test was distributed to the children as a form of "on-going assessment" (cf. § 1.3.3) in order to elicit some more information about children's conceptions on friction after the teaching interventions.

In the teaching intervention in England the role of the teacher was that of a co-ordinator and assistant in the children's investigations, whereas in Greece the teacher seemed to offer a greater degree of guidance, intervening more in the organisation of the educative process. This can be attributed to personal preferences and different

teaching styles of the two teachers involved. Thus, for example, the idea of how to start the investigation came mostly from the children in the study in England, whereas in Greece the idea was basically suggested by the teacher. In both cases though, the role of the teacher was that of helping children to use and develop their own ideas and not merely to present new information and knowledge. Overall, it seems that differences in the teaching style did not appear to have any negative effects in the development of the teaching interventions, or at least they did not appear to affect the expression and discussion of children's preconceptions or the construction new conceptions.

The children in England appeared to express their ideas in a more open way, whereas in Greece they seemed to be a bit more hesitant. It needs to be noted here that the children in Greece were also a bit younger than the children in England. Moreover, they were mostly used to traditional methods of teaching, despite the endeavour of their current teacher to change their attitudes and encourage them to work in a more open and non-threatening learning environment. Nevertheless, the children in both studies expressed some very creative and sometimes rather astonishing ideas throughout the sessions of the teaching interventions. Thus for example, there are many similarities in children's predictions about the sort of pulling force they thought that was needed for the block of wood to start sliding on the tabletop, or on sandpaper.

An unexpected learning outcome in the teaching intervention in Greece was that of friction being symbolised with two opposing arrows (cf. § 5.3). The children in Greece claimed that the two arrows symbolise the two surfaces that get into one another and create friction. Thus, the two arrows pointing in opposite directions appear to be symbolising this interlocking of the "cavities and projections" of surfaces, which appears to have explicit links with the analogy of the two fragments of a jigsaw puzzle. This sort of interpretation of the analogy seems to be one of its possible "side effects" which seems to be creating an alternative, unexpected

expression of the conception. This did not appear in the study in England, perhaps because no such questions about symbolising friction with an arrow were asked during the teaching intervention or in the post-intervention interviews. Furthermore, the "draw the arrow of friction" test was not administered to the children in England, who drew concept maps instead. Nevertheless, this does not mean that the jigsaw puzzle analogy had an overall negative effect in the construction of new ideas about the nature of frictional phenomena. On the contrary, it seems to have helped children to visualise and comprehend the interlocking of the roughness of surfaces and to view friction through such a context. In this sense, it appears to have developed the necessary links between what is already known and a new piece of information, assisting in this way the construction of more advanced conceptions. The interlocking of two pieces, or two larger fragments, of a jigsaw puzzle proved to be a familiar and well established representation in children's minds. Thus, it seems to be an effective *analog* for the *target* situation, which is the interlocking of surface irregularities (cf. § 1.3.2). Moreover, the two additional drawings, which were presented together with the jigsaw, acted as intermediate pictorial representations which reinforced the *metaphorical aspects* of the analogy and helped children to construct new conceptions within the "surface roughness" approximation of friction (cf. §§ 4.2.5, 5.2.2 and Appendix VII). It can be claimed that this analogy has been effective and illustrative in representing the nature of frictional phenomena and it is strongly supported to be used by teachers who choose to approach the concept of friction at the level of primary science education. Nevertheless, we need to be aware of its limitations in the case of "fluid friction" or "drag force" (cf. Appendix 1, p. 3), where it seems to be most unlikely to help children understand various relevant phenomena. Moreover, if it is claimed, in a broader sense, that teachers need a "tool box of analogies" to help learners understand science concepts and phenomena, then it should be pointed out that although it is a fruitful idea, it needs further research in classroom practice in order to become aware of perspectives, limitations and/or side-effects of particular teaching analogies. Only then, I suggest, they can become

valuable items in the teachers' "tool box of analogies" in teaching and learning science at various levels.

In the teaching intervention in Greece, in the second session, an experiment was conducted with a block of wood which was slid on its three different sides in order to show that "friction does not depend on the area of the surface of contact" (cf. National Textbook, p. 126, Appendix VIII). This issue was not approached in the teaching intervention in England because it was not considered as important. Instead it was preferred to discuss further some practical situations. In the study in Greece though, this happens to be part of the material that "needs to be taught", and the teacher insisted on presenting this "property of frictional force", which appears to be rather true or reliable for rough surfaces in contact (i.e. wood over wood) (cf. § 2.2). In the beginning, the children expected and predicted that the greater the area of contact the more friction would be created, due to "more projections and cavities" that would come to contact. After they had experimented with the block of wood on the teacher's table they seemed to be a bit puzzled because the results proved to be counterintuitive. Nevertheless, they managed to reconcile these unexpected outcomes with their initial intuitive ideas by suggesting that "it is still the same block" or "the block of wood still has the same weight", which is "spread" over a larger or smaller area of contact; therefore no change should be needed for the pulling force of the block to start sliding on the tabletop, regardless of which side it is based on the table. In this sense, they appear to have thought of an explanation in terms of an overall pressure, which remains the same for all of the different placements of the block, without using such a term, but by ascribing its meaning to the phrase "the same weight of the block is spread over its different sides". Nevertheless, my opinion is that this so-called "property of friction" is a difficult conception for children of this age. It usually appears in more advanced textbooks together with the other "property" that "friction is proportional to Normal force" and it is a fact that Da Vinci, Amontons or even Coulomb conducted similar experiments to investigate both of these "properties" (cf. § 2.2). But, I think that children of this age do not simply have the

kind of readiness, which presupposes more abstract thinking, in order to understand and explain such issues. This is basically a critique for the Greek national textbook, which rather uncritically forces teachers to teach issues that come out of the wisdom of the curricularist and not out of the curiosity of the child. The results are often controversial, even if in this particular case, the way things have evolved produced a rather unexpectedly fruitful outcome.

On the whole, it can be claimed that the teaching interventions have helped children a lot in constructing new conceptions and in linking them with older ones. In this sense they have helped in the creation of more elaborated and advanced conceptions, promoting conceptual change. The investigations, which have been thoroughly described, are strongly supported for primary educational settings and for teachers who choose to approach frictional phenomena that occur in the interface of two surfaces in contact. It is also suggested that the concept maps, which can be both used as assessment or educative tools, can reveal some aspects of children's conceptions about particular phenomena and it is strongly proposed to be used by teachers who wish to investigate children's propositional links of particular word-concepts. Moreover, children's writing and drawings can be very helpful in assessing or investigating further children's conceptions and their change (cf. §§ 4.2.6, 5.2.4).

6.3.1. A discussion of some methodological issues

From the beginning of this inquiry several methodological issues or questions were brought to the surface and considered carefully. There has been an attempt to resolve them not only during the phase of the planning but also during the development of the research project.

An initial question has been that of the elicitation, presentation or representation of children's conceptions. Within a qualitative research methodology the technique of the interview proved to be effective in the elicitation of children's conceptions coming

out of discussions of particular depicted instances of the interview cards. Moreover, encouraging children to express freely their conceptions and negotiate their meanings with classmates and the teacher, during the teaching interventions, proved to be effective in eliciting further some of children's conceptions, making them explicit to themselves and others, but also ascribing to them some sort of representability (cf. §§ 4.2, 5.2). Children's authentic utterances appear to have revealed a lot about how they think, how they construe the world and construct explanatory statements in order to make sense of particular phenomena. Hence, preconceptions about frictional phenomena and relevant explanations have been elicited in the **Pre-I.I.** and after the teaching interventions, several more advanced conceptions about friction have been elicited throughout the **Post-I.I.** (cf. §§ 4.1, 51, 4.4, 5.4). Concept maps, children's writing and drawings are additional research techniques used in this inquiry in order to represent conceptions or even highlight them from different perspectives (cf. §§ 4.2.6, 4.3, 4.5, 5.2.4, 5.3). Such techniques also appeared to be effective in the representation of children's conceptions of friction and frictional phenomena.

A serious problem which needed a resolution from the beginning has been the elicitation and representation of children's prior knowledge or preconceptions about friction and frictional phenomena without naming them as such. Such preconceptions have been mainly elicited in the pre-intervention interviews (**Pre-I.I.**), where children were asked to explain frictional phenomena without using the word "friction". Instead they were encouraged to discuss their views and to provide descriptions and explanations by using more familiar words like "force", "gripping", "slipping", "rubbing", which implicitly refer to frictional phenomena. This is because it was assumed that an indirect elicitation of preconceptions about friction and frictional phenomena, through a context of conceptions of "force", would provide an elicitation of more in depth, tacit knowledge within a framework of explanations of relative phenomena depicted on the pre-intervention interview cards (cf. § 3.4.). In this sense, it is suggested that children attempt to describe and explain frictional phenomena with what they already know, instead of ascribing particular meanings to what might, to

them, be a rather unfamiliar word like "friction" and attempt to use it in their propositional statements. This has been achieved with the help of "key questions" which appear to draw attention on frictional phenomena and probe the discussion further in terms of children's attempts to explain them. It seems that several preconceptions about frictional phenomena have been elicited in this way, together with other more or less relevant conceptions that referred to the depicted instances (cf. §§ 4.1, 5.1). Furthermore, this approach is strongly related with the teaching interventions that follow the **Pre-I.I.**, since the concept of friction is mainly discussed and investigated within a framework of educative procedures whose outcomes are considered seriously in the development of children's conceptions, which are also elicited in the **Post-I.I.**. Hence, in this inquiry, **Pre-I.I.** have not been conducted irrespective of what children are taught in school, but on the contrary they are incorporated within a more holistic approach which involves a teaching intervention and **Post-I.I.** It was kept in mind that children would have a second chance to explain frictional phenomena after the teaching interventions by using more elaborated or advanced nomenclature or at least by having ascribed new, more thoughtful meanings to words they had already used in the **Pre-I.I.** Of course, it can always be claimed that if things had been designed differently, different results would have appeared. Perhaps different depicted instances would have elicited different conceptions, but this is more clearly seen after the conduct of the interviews and the analysis of data. Perhaps the use of the word "friction" in the **Pre-I.I.** would have probed children to express their views about frictional phenomena in different ways, or they could be forced to ascribe to it spontaneous and imaginative meanings constructed at the time of the interview, but again this seems to be another *a posteriori* possible conjecture. Hence, it seems to me that most of the choices a researcher adopts during the development of a project, which determine the outcomes to a great extent, appear to be time and context dependent.

The problem of identifying and highlighting some aspects of children's conceptual change has been a crucial one from the beginning of this inquiry. It also had to be

seen in combination with the teaching interventions and the interviews conducted before and after them. It has been assumed that a comparison of children's thinking and reasoning before and after the teaching interventions would reveal some aspects of their conceptual change, in the way they view and explain particular phenomena. This assumption appears to be corroborated by the fact that a similar methodology has also been used in other research projects such as SPACE (1990; 1991;1992) (primary school science) and CLISP (e.g. 1987; Wightman, 1986) (secondary school science), in order to elicit, represent and discuss learner's conceptions and conceptual change.

The CLISP is more oriented to secondary school science, with an emphasis on the elicitation of children's conceptions through responses to written questions, which is not considered to be as suitable for primary children, where an interaction with real objects and events appears to be more appropriate (Russell *et al.* 1989). The SPACE project has developed, in collaboration with teachers, techniques for finding out children's ideas in the context of classroom activities. These techniques include open questioning, asking children to draw and annotate their drawings (for younger children the teacher may annotate in discussion with them), encouraging children to write about or talk about their ideas, listening to children in discussion with each other, as well as with the teacher. The overwhelming conclusion from studying children's ideas on a wide range of scientific topics is that they are the product not of childish imagination, but of reasoning (Harlen, 1992b). Usually, the research methodology in SPACE is as follows: children are interviewed or tested before and after a teaching intervention, on a certain science topic, and their respective conceptions are compared in order to investigate and discuss anticipated conceptual change. Quite often children's writing and drawings are also used to provide additional information about their conceptions and to cross-examine them with the results from the analyses of the interview data. In this sense, it could be claimed that this inquiry follows a similar route in methodology with that of SPACE in an attempt promote and investigate some aspects of children's conceptual change.

6.3.2. A note on the "authentication" of the research outcomes

In educational research, events are not observed without themselves being inevitably changed and shaped by the interpreter. In this sense, research findings do not represent a fixed objective reality but something which is holistic, multi-dimensional and ever-changing. As it has been argued in chapter 3 (cf. p. 79), psychometric notions of validity and reliability do not appear to be compatible with the *verstehen* research tradition (cf. pp. 74-75) or with a *second-order perspective* (cf. p. 76) that this research project has adopted. Nevertheless, some issues concerning the *authenticity* of research data and relevant analyses need to be addressed.

This inquiry attempts to reveal children's conceptions of friction and frictional phenomena and investigate some aspects of their conceptual change. This means that it seeks to investigate some aspects of children's constructions of reality, or their understanding of the world, so its *authentication* rests upon how adequately children's multiple mental constructions are elicited, represented and discussed. Such a notion of *authentication* in this research project is considered to have been achieved by talking directly to the learners, probing their conceptions and explanations about friction and frictional phenomena, making sure that they really have a chance to express their understanding of a concept. This refers both to the interviews and the teaching interventions. Furthermore, children's expressions and language have been used in the formation of interpretative statements in the interview analyses, or in the conduct and presentation of the teaching interventions, within authentic educational settings.

6.4. Some points of self-critique and implications for future research

In this inquiry there has been an attempt to approach the issue of conceptual change in a holistic way, in terms of methodology and interpretation. This involves teaching interventions and interviews before and after them, together with some assessment

techniques, which all aim to promote and investigate conceptual change. In my opinion, the initial aims of the inquiry (cf. General Introduction) have been fulfilled to a great extent, although there are always the thoughts in a researcher's mind about things that could be done in a different or a "better" way, but these are often the product of post-conjectures, within an intersubjective context of critique. Nevertheless, the notion of a holistic approach adopted in this inquiry aims to be a constitution of "something more" than the accumulation of its parts. This means that the interdependency of its various parts or phases aims to constitute an overall synthesis, which is considered to be the necessary condition if one seeks to investigate and interpret the phenomenon of conceptual change, within the particular context of teaching and learning about frictional force in primary science education. This approach has created a number of problems in the organisation and conduct of the research. Hence, a lot of time has been consumed or invested in the planning, conduct, analysis, interpretation and reporting of a research project, where several phases and stages are involved. The greatest difficulty of all has been that of pulling together the strings of research procedures and educative processes full of detailed components, in an attempt to create a comprehensive synthesis.

The fact that the research was conducted in two countries and in two different languages created more problems in the elicitation of the interview data and the conduct of the teaching interventions. Moreover, the fact that the reporting of this research project had to be written only in one of the two languages involved (English) has created problems in the translation and transition of meanings and conceptions from one language to the other. Nevertheless, the thesis appears to provide a detailed report of *what* and *how* things have happened, together with discussions and interpretations of particular events, in each of the phases of the project. Hence, it is my opinion that educators and researchers who wish to repeat parts of the research procedure or check the outcomes of a particular aspect of the project, have the necessary details to do so. In this sense, all of the thesis is subject to the critical eye of the reader.

This inquiry has been *phenomenographic*, within a *second-order perspective*, in the sense that it reports people's ideas about the world (cf. § 3.1), but also a research into particular events, therefore a study of *singularity* (cf. Bassey, 1995). Thus, it does not aim to make generalisations beyond its scope, since it aims to understand particular events and suggest some interpretations about particular children's conceptions and conceptual change, within the context of frictional force. It would be interesting to see to what extent the ideas discussed in this inquiry are representative in larger samples of children, using similar or more quantitative research methods. It would be also interesting to see how children of non-Western cultures would react to the same research procedures and what kinds of conceptions and conceptual change would they reveal. Moreover, it would be challenging to investigate the extent to which the "weak" form of conceptual change that has been described and supported in this inquiry is a more generally fruitful idea for other basic concepts, which are taught in primary science classrooms. These considerations are some of the implications for future research in the field of conceptual change teaching and learning that this inquiry has to suggest.

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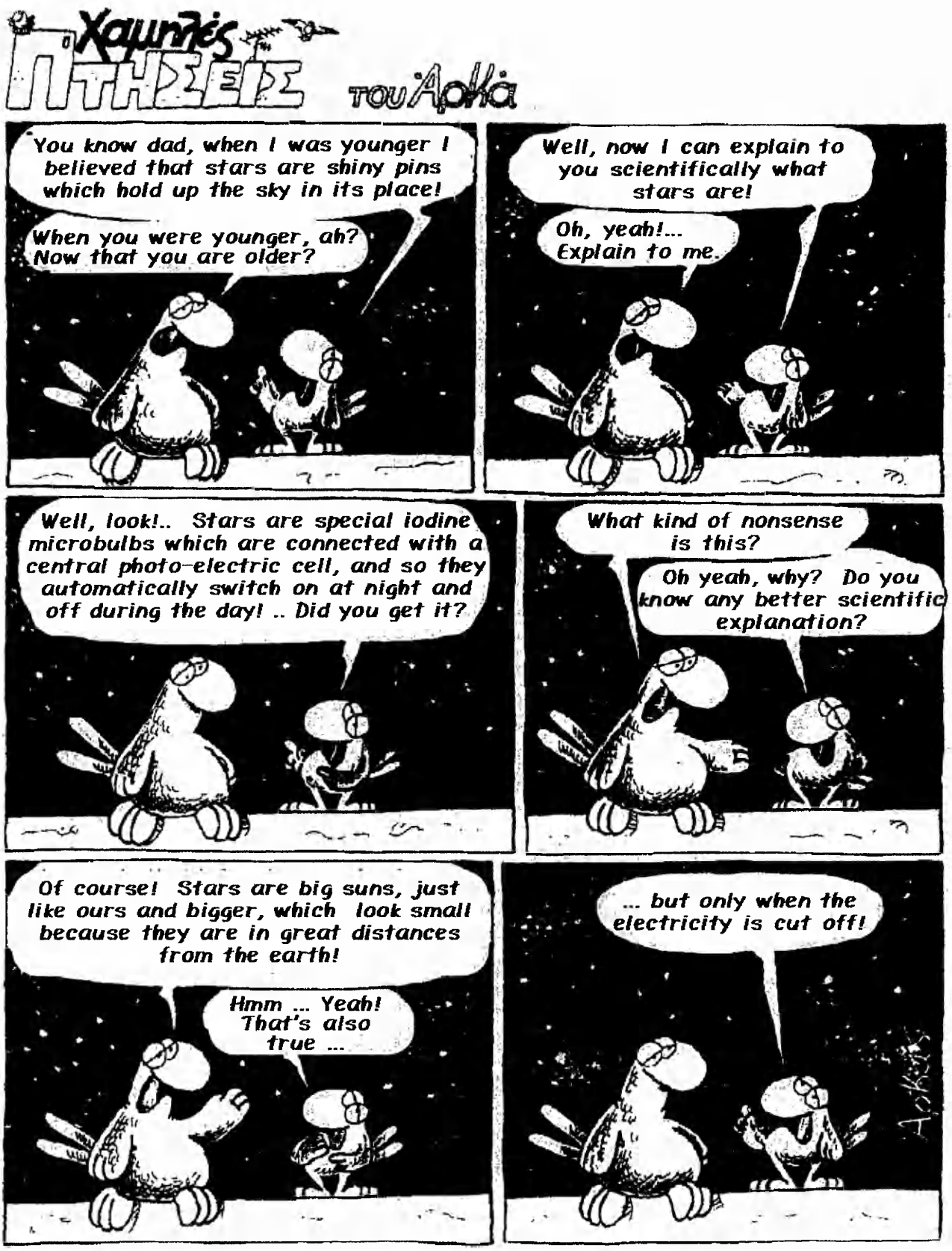
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APPENDICES



"Arkas", one of my favourite cartoonists, has expressed, in his own characteristic and graphic way, his conceptions of "children's ideas" or "preconceptions", which are "resistant to change", or the ideas of the "ACM" and the "children thinking in two domains" opinion.

Source: The Sunday "**E**" , 27-3-1993. Translation is mine.

APPENDIX I

$A_1.1$. The concept of rolling friction

The friction that opposes the rolling of a body over a surface is observed to be much less than the friction of a sliding body over a surface and this indeed is the advantage of the wheel over the sledge. The use of wheels and cylinders in order to eliminate friction is an everyday process. It is common experience that any rolling wheel eventually will come to rest and we understand that the reason is friction between the wheel and the surface. This **rolling friction** is rather different from static or kinetic (sliding) friction and requires a more careful examination.

Consider an isolated wheel, perfectly circular that rolls across a flat surface at constant velocity v (see fig. 1, diagram *(a)*). If we construct an equivalent force diagram, we can visualise the forces acting on the wheel which are the gravitational force F_g and the normal force N, which are equal in magnitude, opposite in direction and on the same vertical axis that passes trough the (theoretical) point of contact. This is an ideal situation where the wheel remains perfectly round and the surface perfectly flat and no slipping or deformation of any kind occurs; thus there is only a single point of contact (which is actually a line) of the wheel and the surface.

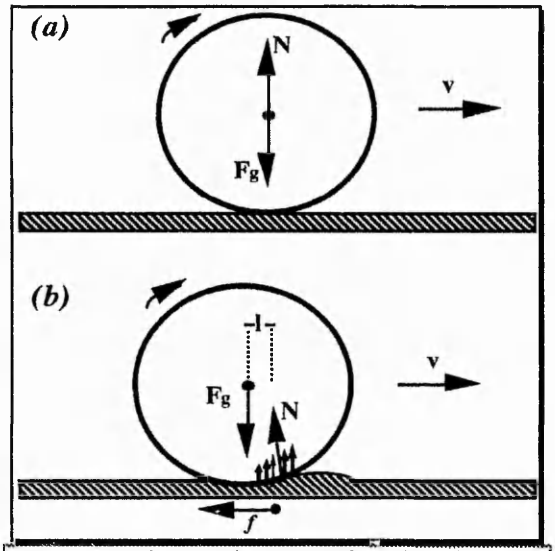


Fig. 1: *(a)* the forces acting on a perfect wheel that roles across a flat surface and *(b)* an exaggerated schematic representation of a wheel rolling across a surface. Both the wheel and the surface are deformed.

Under these ideal conditions we have assumed, there is no instantaneous relative motion between the wheel and the surface at the single point (line) of contact, so there is no mechanism that can cause frictional losses. Thus, we are forced to conclude that there is no frictional force and the wheel will roll at constant velocity. Clearly, from the perspective of common experience from our 'frictional' world, the surface cannot have such an effect on the wheel, when we all know that wheels eventually stop rolling, provided that there is no force pushing or pulling them.

In a *real* case, the diagram *(a)* in fig. 1, is incorrect in several respects. First, both the wheel and the surface suffer deformations to an extent which depends on their particular elastic qualities. The diagram *(b)* in fig. 1 shows an exaggerated pictorial

representation of these deformations. The lower portion of the wheel is flattened and a shallow trench is formed in the surface. The 'line of contact' between the wheel and the surface has been expanded to a sizeable area. The normal force is now distributed over the area of contact. As the wheel rolls forward, its leading portion and the respective contact area are compressed while the trailing portion becomes relaxed and as a consequence the deformations are greater forward the centre of rotation. A large deformation is associated with a large force (Hook's law); hence, the individual normal forces acting on various parts of the wheel are greater in the forward section. Thus, the gravitational force F_g and the resultant normal force N are now in distance l from each other (see fig. 1, diagram *(b)*). These two forces constitute a *couple*, since they are a system of two equal in magnitude, but oppositely directed forces. This couple creates a *torque* which hinders the rolling of the wheel. This torque can be called **rolling friction** and it actually reduces the angular speed of the wheel. If the wheel is left alone (not driven), it will stop rolling after a while, unless an external force is constantly applied to it, in order to continue its movement. It is evident that what is usually said about rolling friction being "less than sliding friction" is a false statement. They cannot be compared, since sliding friction is a *force* while rolling friction is a *torque* (Halliday, Resnick & Walker, 1993, p. 322).

The nature of friction in rolling motion is very complex. As the wheel and the surface deform during the rolling motion, some slippage also occurs. Thus, sliding friction is also present, to a certain extent. In fig. 1 diagram *(b)*, it is sliding friction that is symbolised as f.

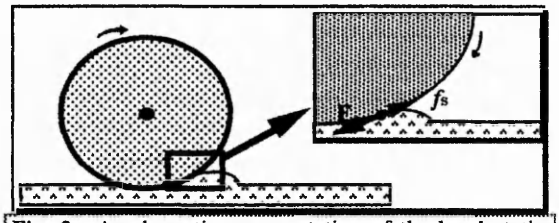


Fig. 2: A schematic representation of the local static friction at a certain point of contact of a rolling wheel and the ground.

However, the primary frictional effect over the area of contact is one of static friction. At the local level of contact of the wheel with the ground, there is *a local static friction* which is exerted from the ground to the wheel and it is opposite to the direction of the movement of the points of contact of the wheel as they come in touch with the ground. Thus, for a certain point of contact (see fig. 2), there is static friction f_s, which is opposite to F, which is the force that the wheel exerts on the local points of contact, due to its rotation and it is tangential to its circumference. Strangely enough, this local static friction has the same direction of the motion of the axle of the wheel (*translation*), which is a forward motion. Without the existence of this local static friction, it would be impossible for the wheel to be 'extended' on the ground and therefore its rolling would be impossible.

In most cases, the important source or frictional losses is the deformation process. No real material is perfectly elastic, so there are always energy losses when a material is compressed and then relaxed. This continual deformation-relaxation cycle generates heat in the wheel and the surface. This is why the automobile tires become hot when they are run at high speeds.

A_1.2. The special case of a 'drag force'

A swimmer experiences some kind of 'frictional drag' exerted on her by the surrounding water. Atmospheric drag impedes the forward motion of an aeroplane or an automobile, but makes possible the operation of a parachute. There is a ***drag force*** which tends to retard the motion of any object that moves through a fluid such as air or water. The measure of the resistance to flow that a fluid offers when it is subjected to shear stress is called **viscosity**. Air resistance is often considered in textbooks as 'air friction' (Jennings, 1993, p. 83). On the other hand, McCleland (1991) in a reply article to Salazar et al. (1990), put forward some doubts and reservations concerning the misuse of this kind of nomenclature for the description of various frictional phenomena. He claims that the widespread use of the term 'friction' to describe different phenomena may cause problems to students, on the grounds that distinct phenomena should be given different names. Thus, he concludes that "*friction should be restricted to situations where two surfaces of solids are in contact and in relative motion. Where two surfaces are in contact but not in relative motion it is proposed that the interaction along the interface be called 'shear adhesion'*" (p. 237). This also depends on the model of approximation and/or description of the phenomenon. He also argues that making the surfaces as smooth as possible *reduces* friction, while the use lubricants or interposing wheels or rollers *eliminates* friction, giving additional emphasis in the use of these verbs in various instances in textbooks.

Bearing in mind McCleland's (1990) recommendations, one could claim that although the 'drag force' *is* a distinct phenomenon, it also refers to practical considerations which could provide fruitful explanations within a broader sense of the concept of friction.[1]

[1] In this respect, air resistance is used in a couple of instances which are depicted in the interview cards which aimed to elicit children's ideas on the relevant topic, within the context of this inquiry.

$A_1$3. Properties of friction in more abstract terms

If we experiment with a body that is pressed against a surface (both remain dry and unlubricated) and we attempt to slide it over the surface by exerting a force **F** to it, the resulting frictional force can be identified by the following three properties which express, in rather more abstract terms, the "laws" of friction that were presented qualitatively in chapter 2:

Property 1. If the body remains stationary, then the magnitudes of the static frictional force $\mathbf{f}_s$ and the component of **F** that is parallel to the surface are equal and $\mathbf{f}_s$ has an opposite direction of that component of **F**.

Property 2. The magnitude of the static frictional force $\mathbf{f}_s$ has a maximum value $f_{s,\max}$ that is given by

$$f_{s,\max} = \mu_s N$$

where μ_s is the **coefficient of static friction** and N is the magnitude of the normal force, which is perpendicular to the surface of contact. If the magnitude of the component of **F** that is parallel to the surface exceeds the value of $f_{s,\max}$, then the body begins to slide along the surface[2].

Property 3. When the body begins to slide along the surface, the magnitude of the frictional force decreases to a value f_k given by

$$f_k = \mu_k N$$

where μ_k is the **coefficient of kinetic friction**. After the body starts sliding on the surface, the magnitude of the kinetic frictional force f_k is given by the preceding equation and its direction is parallel to the surface of contact and opposite the intended motion (Halliday, Resnick & Walker, 1993, p. 134).

The coefficients of friction μ_s and μ_k are dimensionless and experimentally determined. They are primarily a property of the contacting materials and depend on many variables, such as surface finish, surface films, temperature and the extent of contamination in the interface (Halliday & Resnick, 1981, p. 100).[3]

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[2] In properties 1 and 2 the force **F** is considered as a single force exerted on the body. Things would be the same for the resultant force acting on the body, as a result of several forces acting on it.

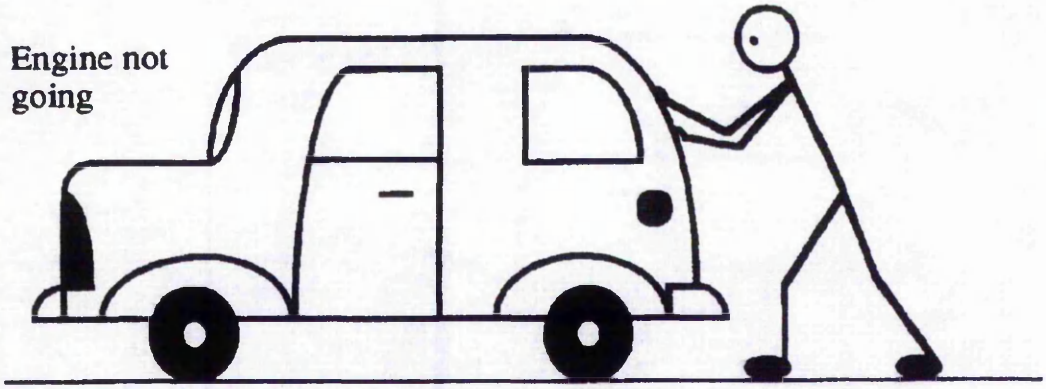
[3] Generally, it is observed experimentally that $\mu_s \rangle \mu_k$.

APPENDIX II

THE STUDY IN ENGLAND

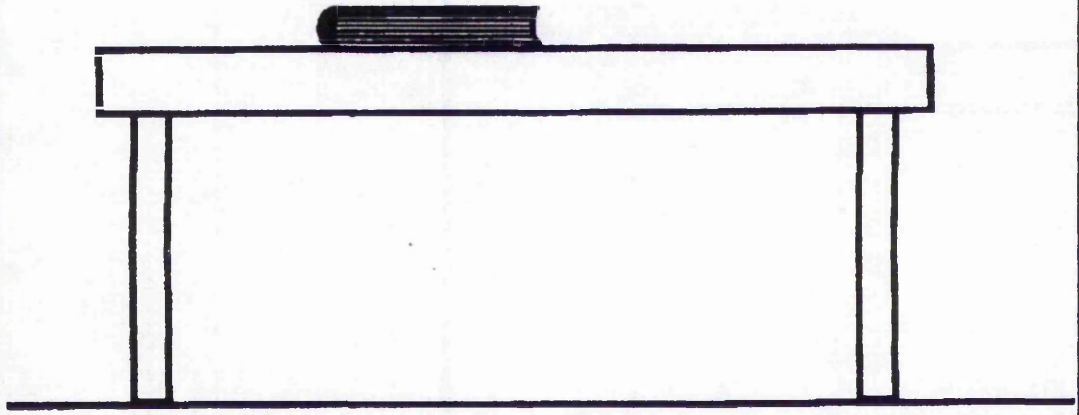
Pre-Intervention Interview Cards

The man is trying to move the car, but the car is not moving



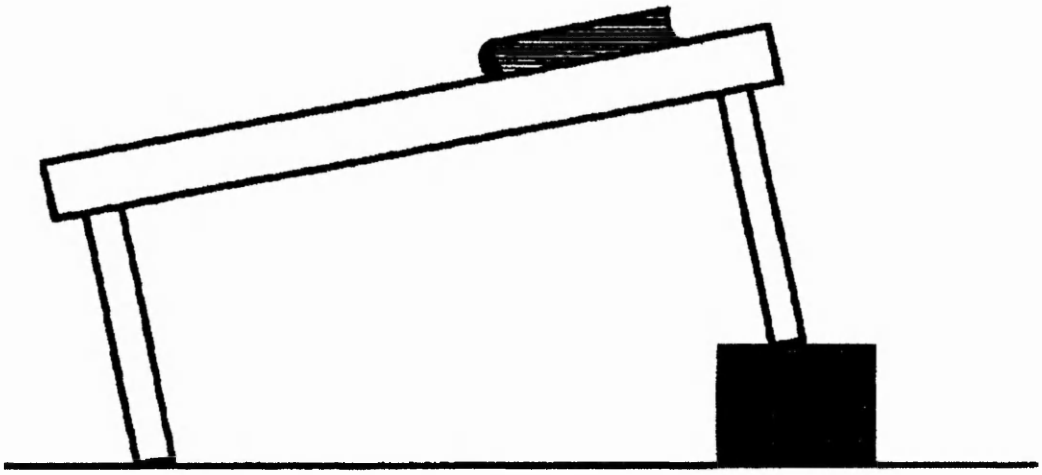
Is there a force on the car?

There is a book on the table



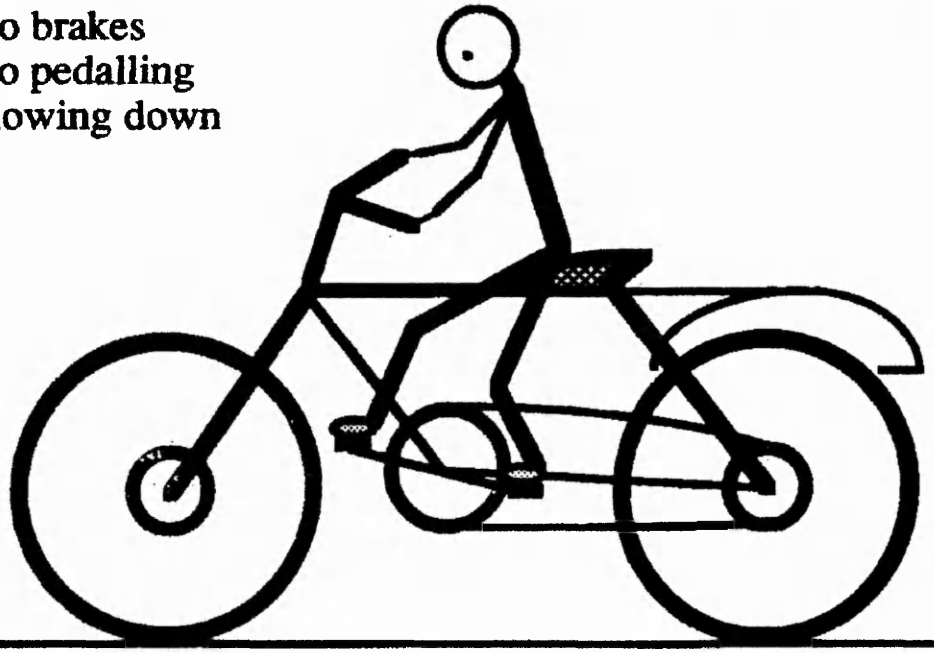
Do you think there are any forces here?

We lift the table up a little bit from one of the sides.
The book does not slide down.



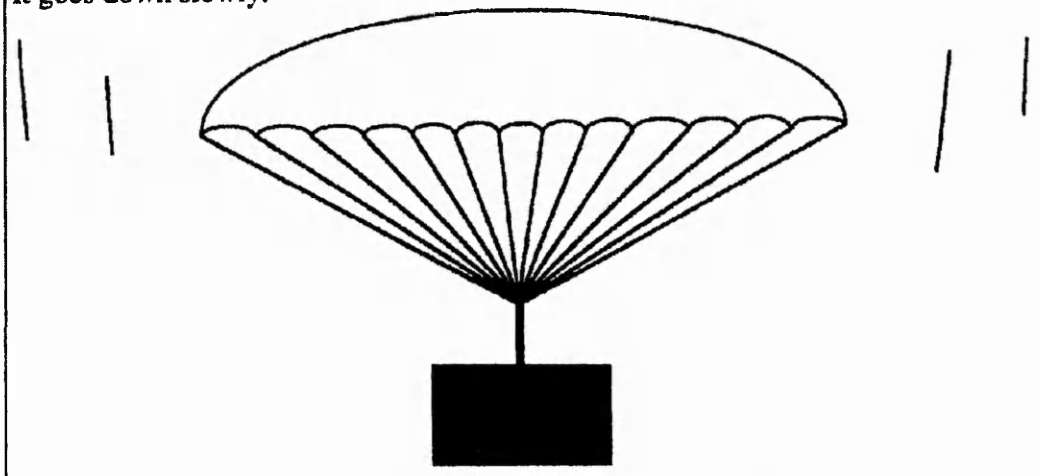
Do you think there is any force keeping it there?

No brakes
No pedalling
Slowing down



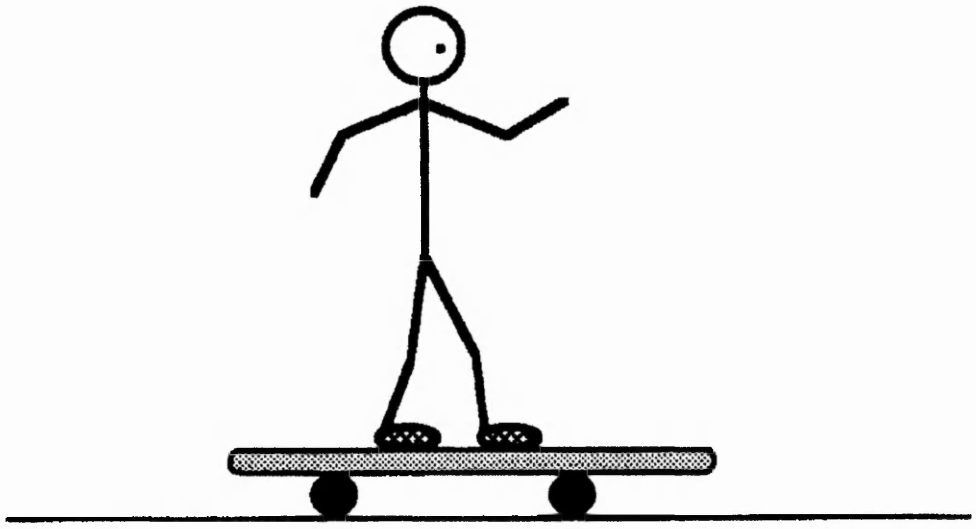
Is there a force on the bike?

A box full of food and medicines was dropped with a parachute from an aeroplane. It goes down slowly.



Do you think there are any forces here?

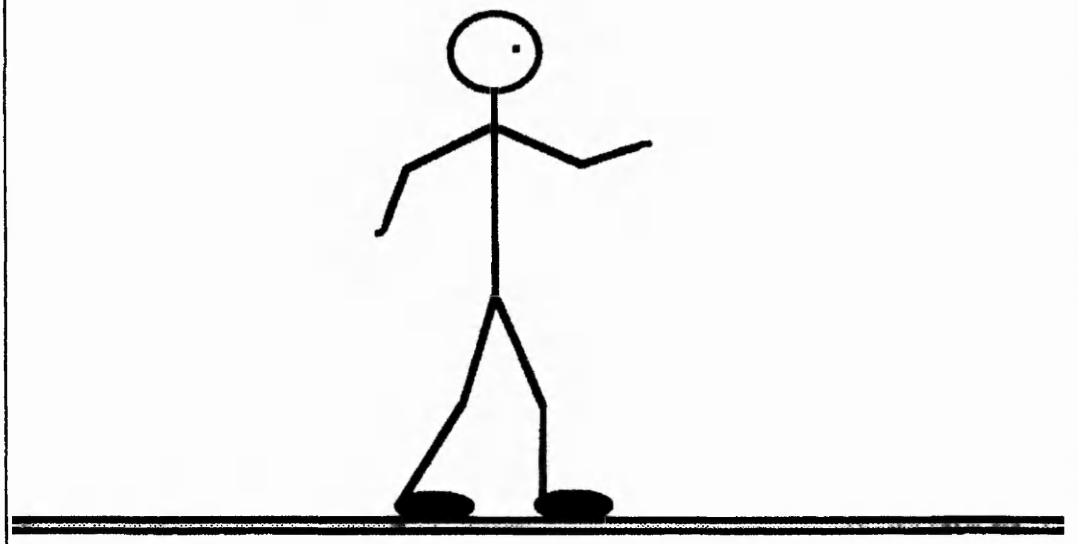
Rolling with the skateboard. No pushing. Slowing down.



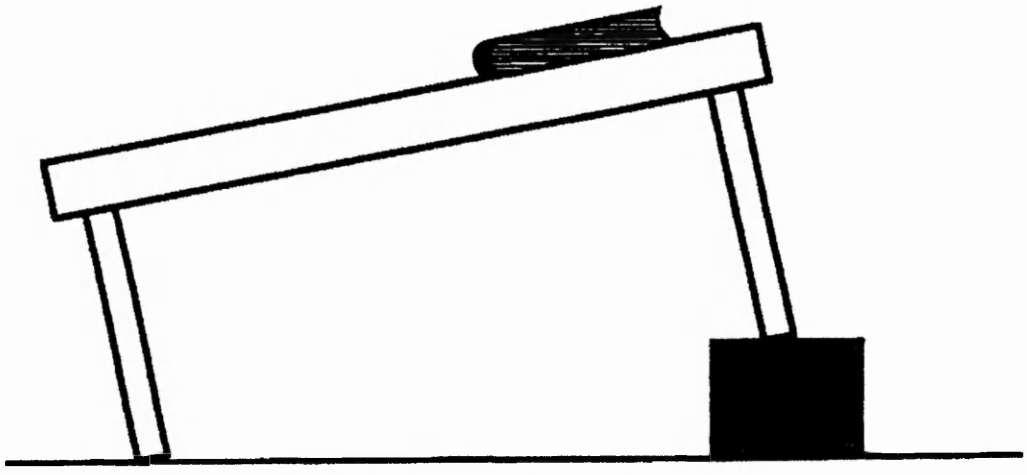
Do you think there are any forces here?

Post-Intervention Interview Cards

Walking along the road. Is there any friction here?

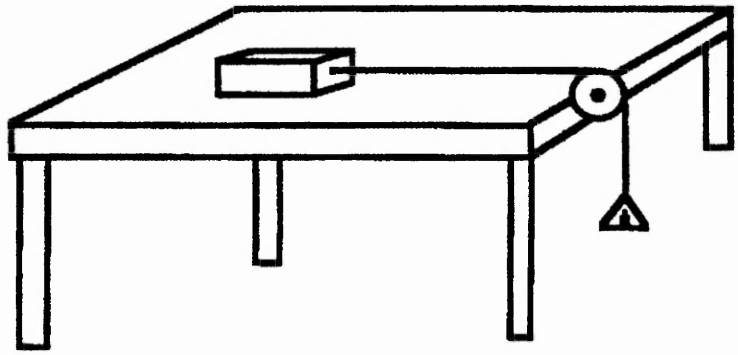


We lift the table up a little bit from one of the sides.
The book does not slide down.



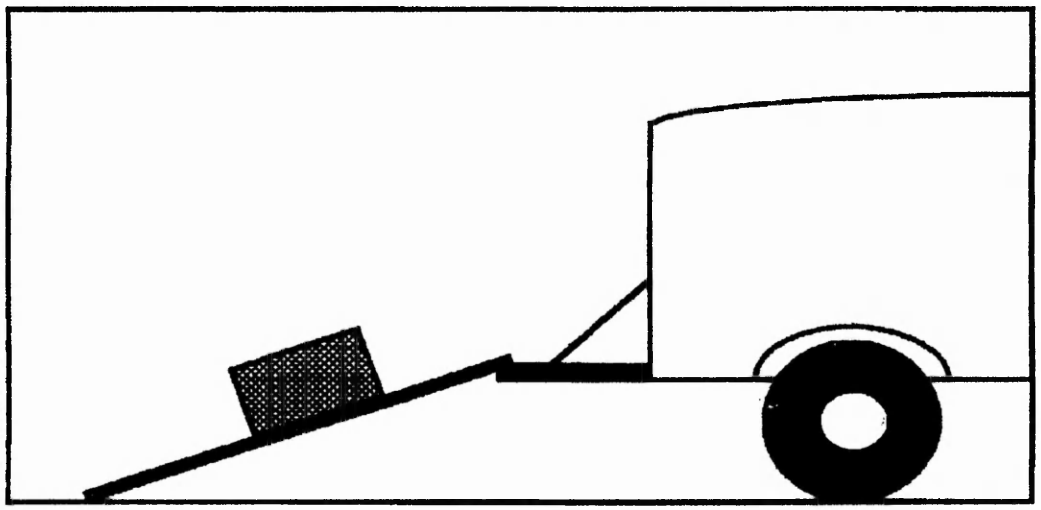
Do you think friction is keeping it there?

There is some weight in the tray, which is under the pulley at the end of the string. But the block of wood does not slide on the table.

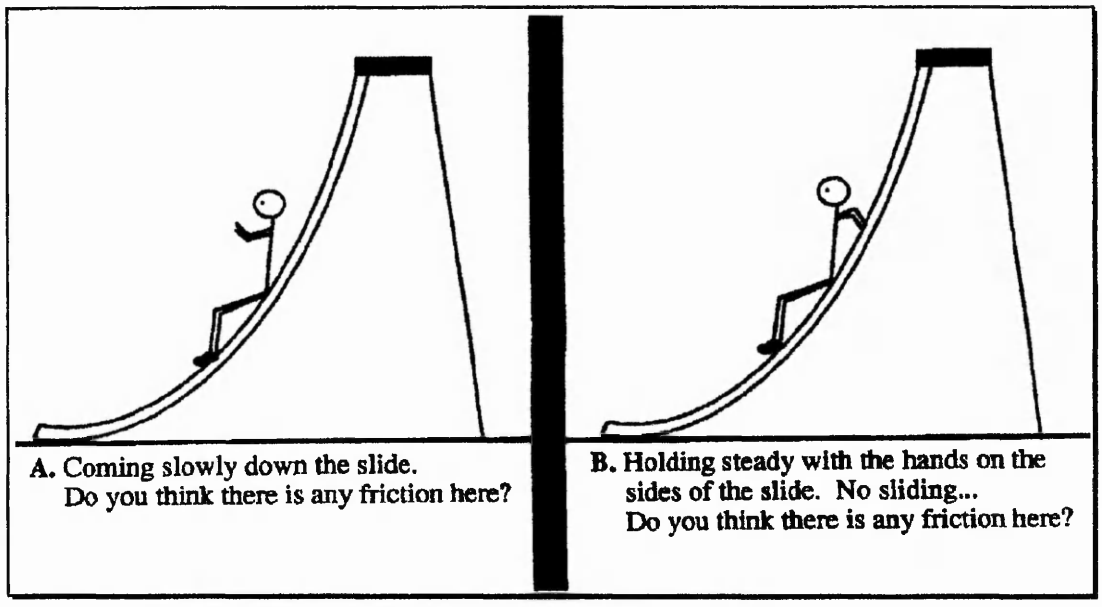


Do you think friction keeps it there?

There is a box left on a slope at the back of a truck. It is not sliding down...

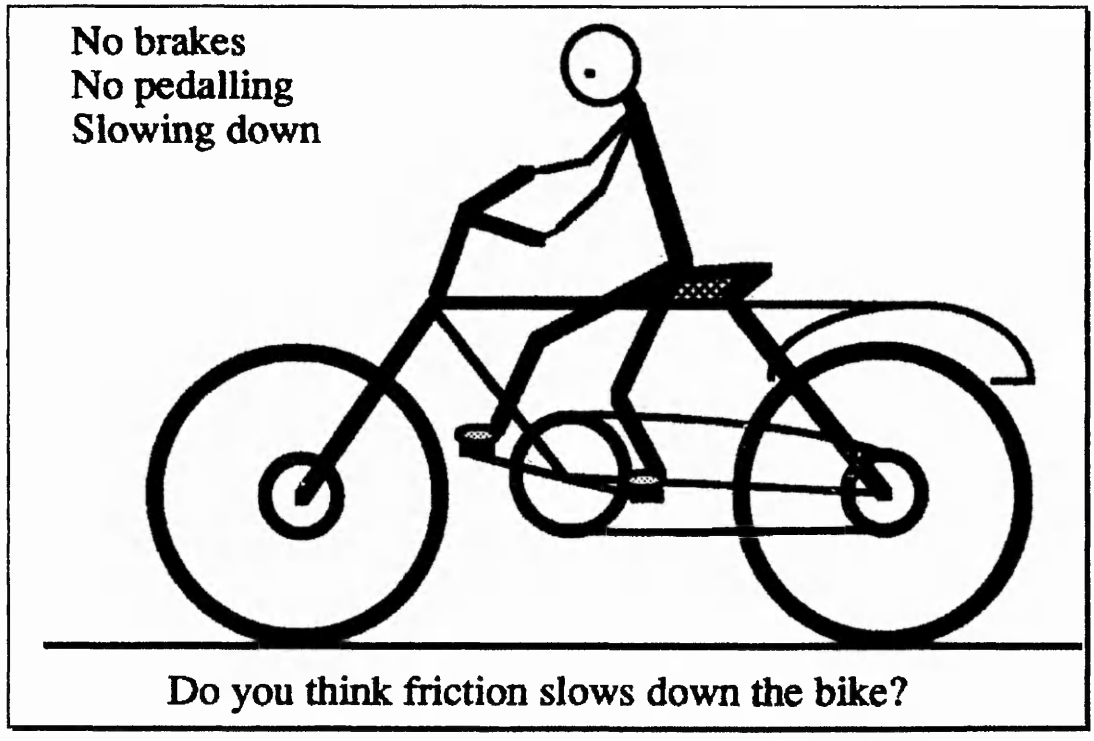


Do you think there is any friction here?



A. Coming slowly down the slide.
Do you think there is any friction here?

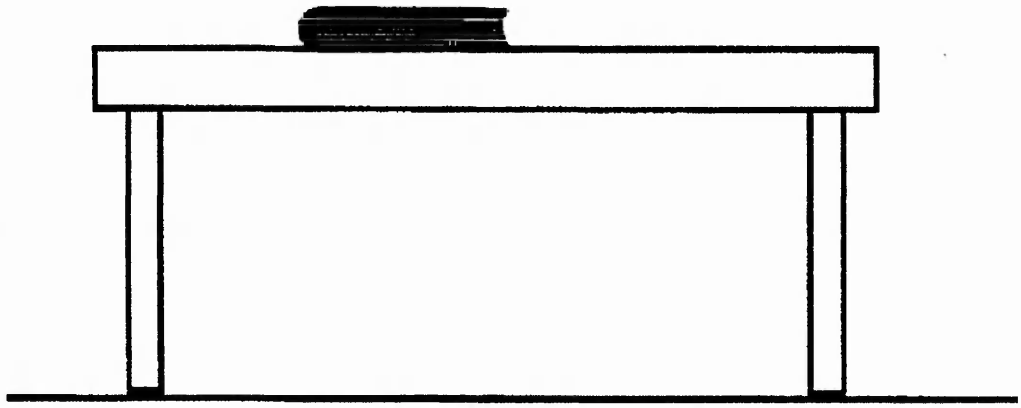
B. Holding steady with the hands on the sides of the slide. No sliding...
Do you think there is any friction here?



THE STUDY IN GREECE

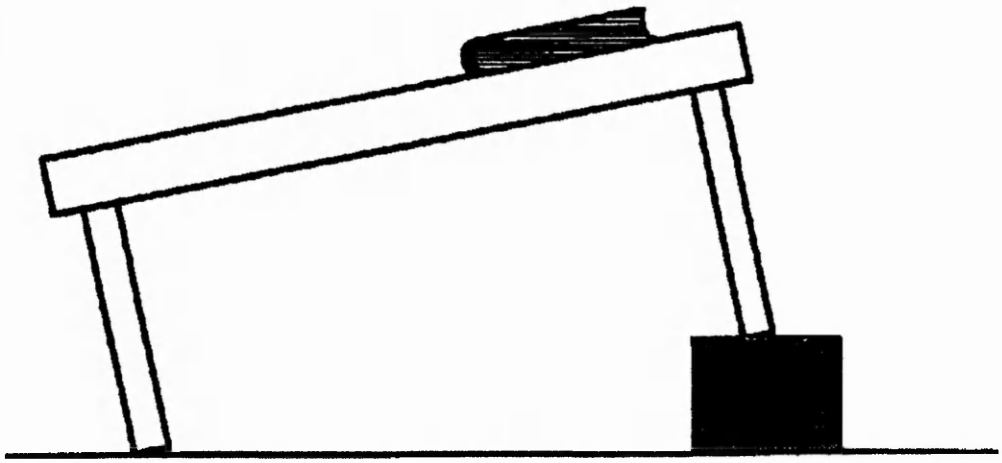
Pre-Intervention Interview Cards

Υπάρχει ένα βιβλίο πάνω στο τραπέζι.



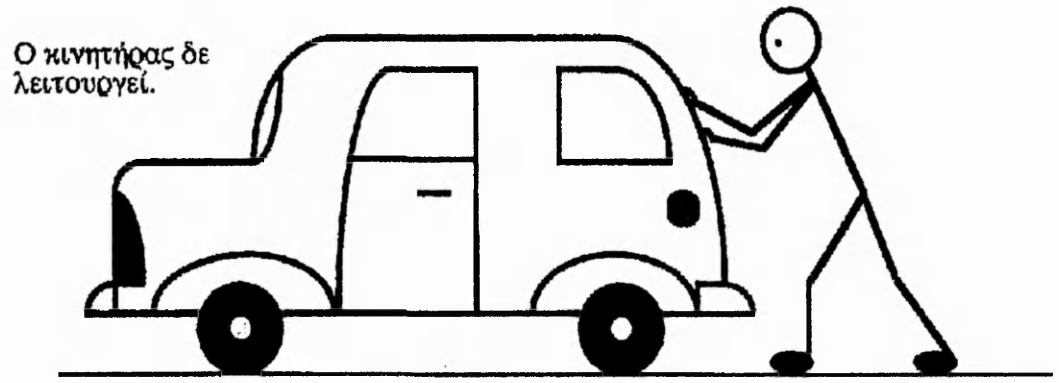
Νομίζεις ότι υπάρχουν δυνάμεις εδώ;

Σηκώνουμε λίγο το τραπέζι από τη μια μεριά.
Το βιβλίο δεν τσουλάει πρός τα κάτω.



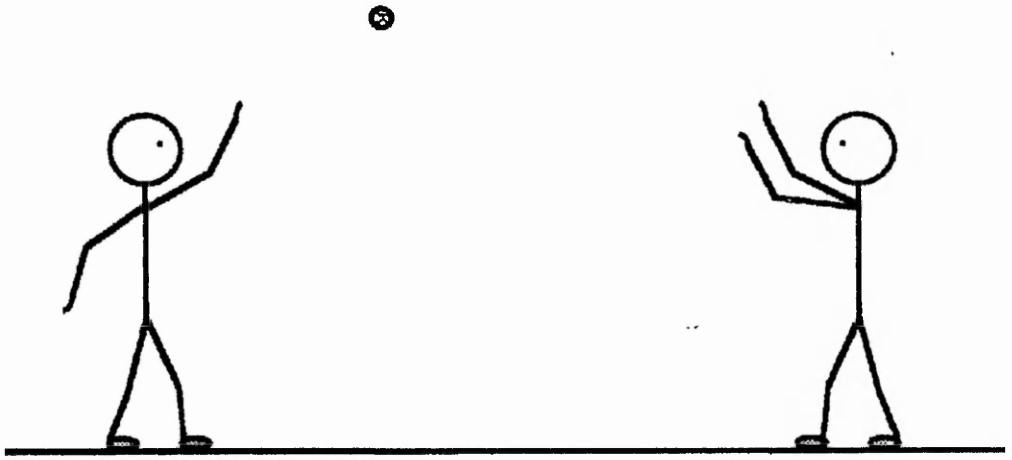
Νομίζεις ότι υπάρχει κάποια δύναμη που το κρατάει εκεί;

Προσπαθεί να μετακινήσει το αυτοκίνητο, αλλά αυτό δεν μετακινείται.



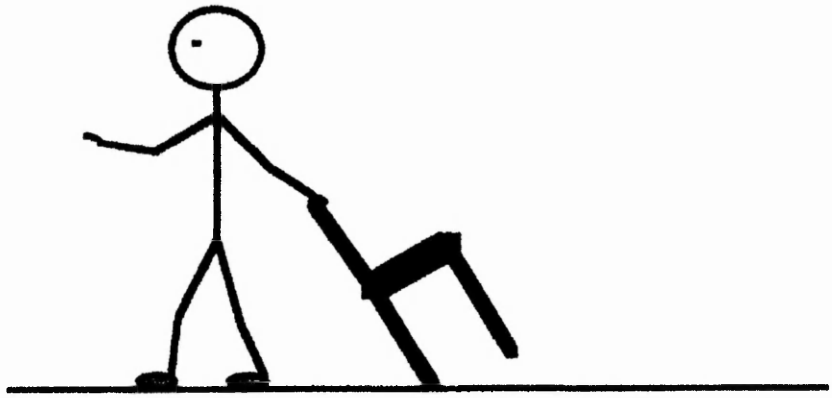
Ασκείται καμία δύναμη στο αυτοκίνητο;

Πετάει το μπαλάκι στο παιδί που βρίσκεται απέναντι...

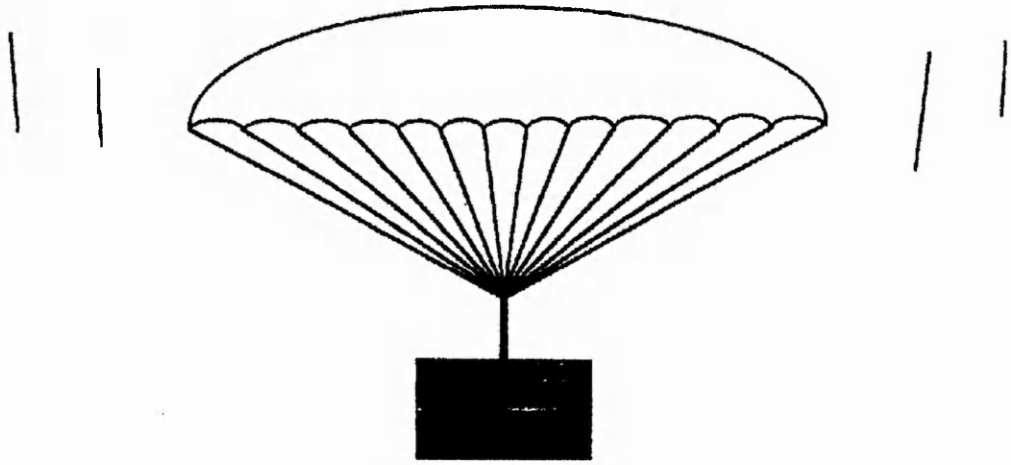


Νομίζεις ότι ασκούνται δυνάμεις στο μπαλάκι;

Τραβάει το καρεκλάκι. Νομίζεις ότι ασκούνται δυνάμεις εδώ;

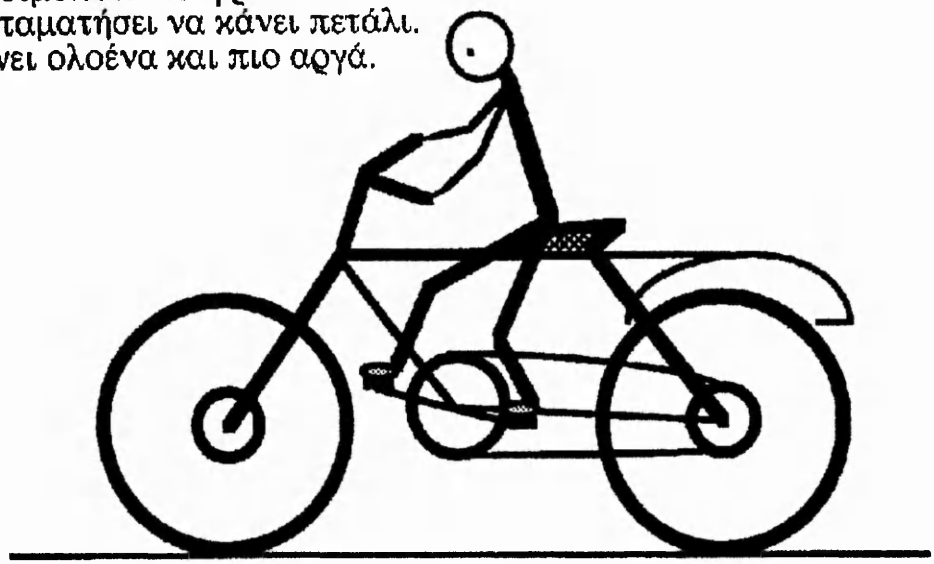


Ένα κουτί γεμάτο με τροφές και φάρμακα πέφτει με αλεξίπτωτο από ένα αεροπλάνο.



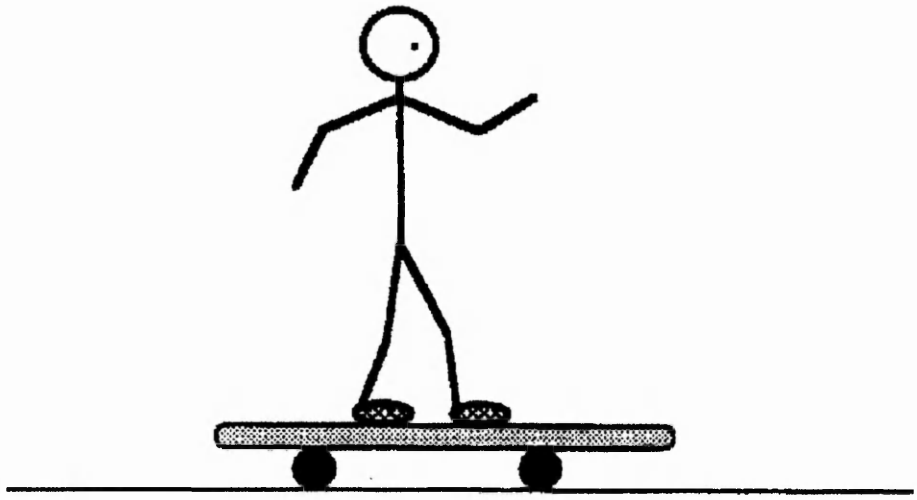
Κατευθύνεται αργά προς το έδαφος. Νομίζεις ότι υπάρχουν δυνάμεις εδώ;

Δε χρησιμοποιεί τα φρένα.
Έχει σταματήσει να κάνει πετάλι.
Πηγαίνει ολοένα και πιο αργά.



Ασκείται καμία δύναμη στο ποδήλτο;

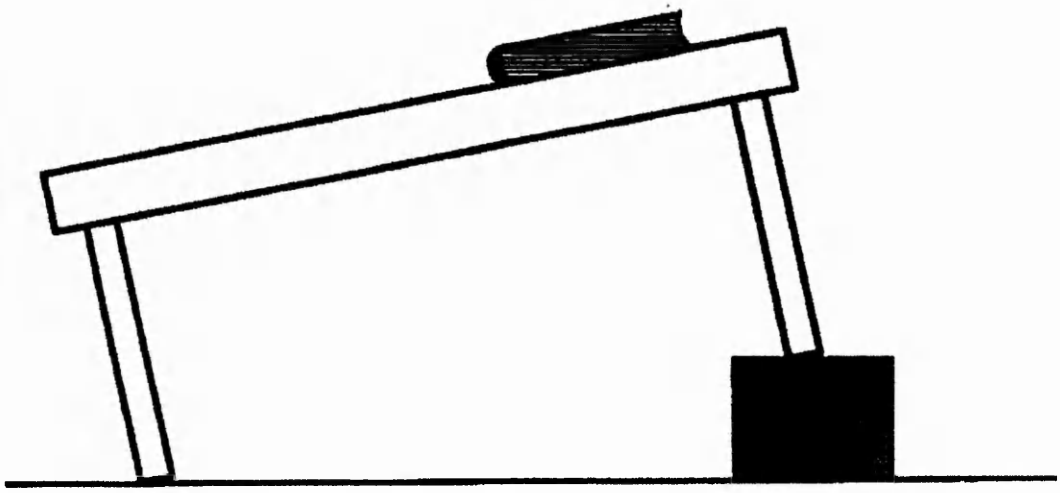
Προχωράει με το σκέϊτμπορντ. Δε σπρώχνει με το πόδι.
Πηγαίνει ολοένα και πιο αργά.



Νομίζεις ότι υπάρχουν δυνάμεις εδώ;

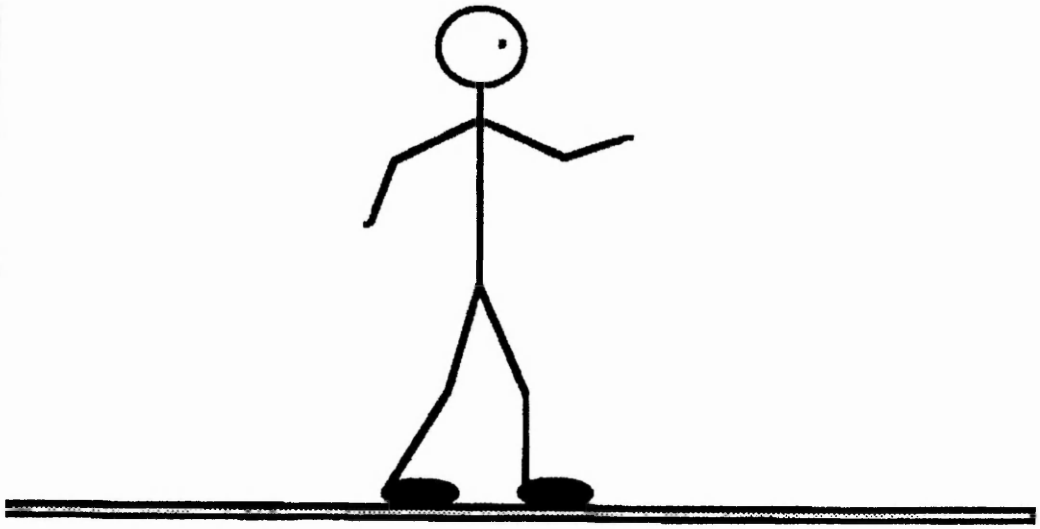
Post-Intervention Interview Cards

Σηκώνουμε λίγο το τραπέζι από τη μια μεριά. Το βιβλίο δεν τσουλάει πρός τα κάτω.

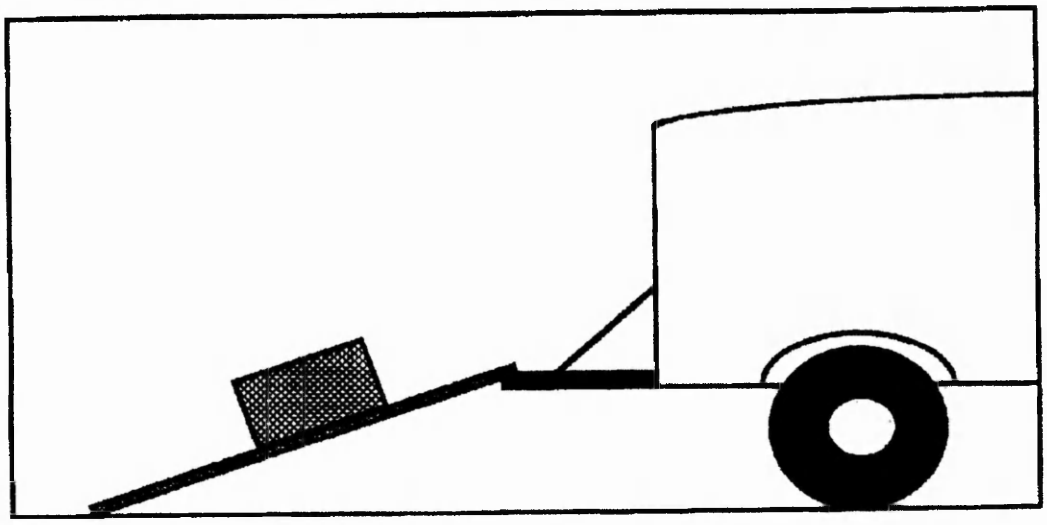


Νομίζεις ότι η τριβή το κρατάει εκεί;

Περπατάει στο δρόμο. Νομίζεις ότι υπάρχει τριβή εδώ;

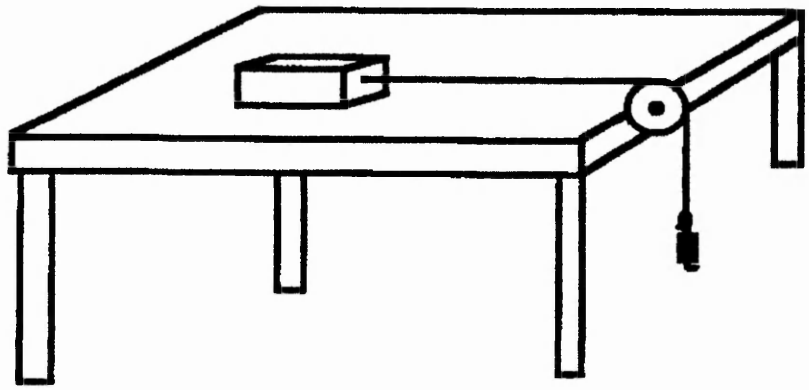


Υπάρχει ένα κουτί πάνω σε μια σανίδα στο πίσω μέρος ενός φορτηγού. Το κουτί παραμένει στη θέση του. Δεν τσουλά...



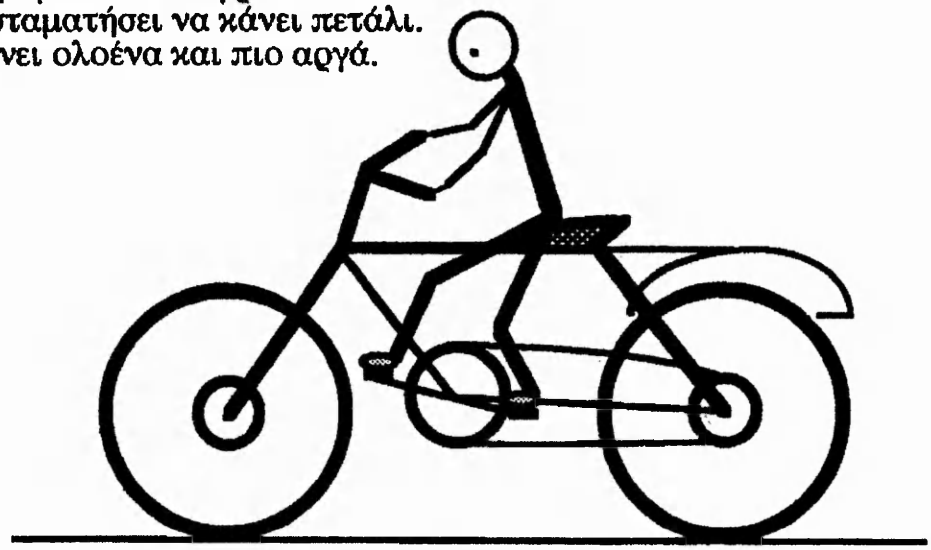
Νομίζεις ότι υπάρχει καθόλου τριβή εδώ;

Υπάρχει ένα κομμάτι ξύλου πάνω στο τραπέζι. Στο ξύλο αυτό ασκείται μία δύναμη από το βαράκι που κρέμεται στην άκρη του σπάγγου. Το ξύλο, όμως, δεν κινείται...

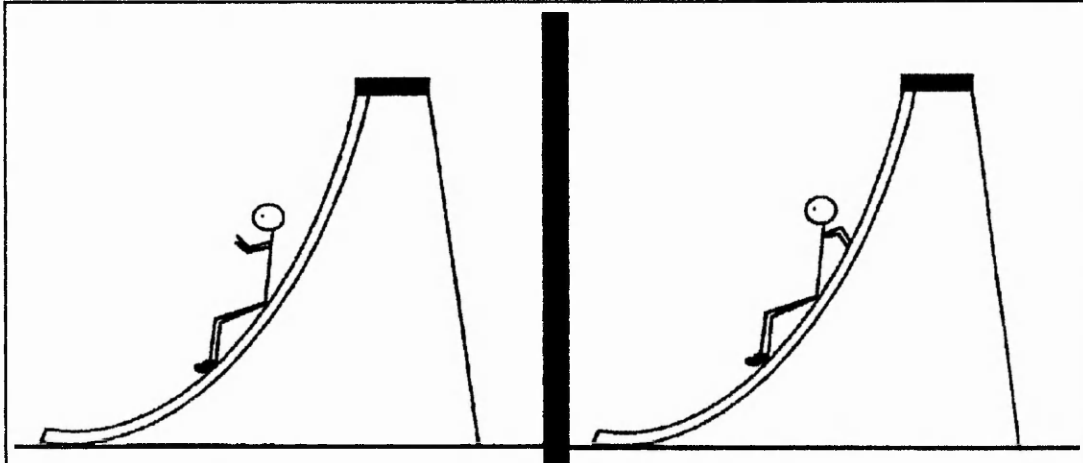


Μήπως νομίζεις ότι η τριβή το κρατάει εκεί;

Δε χρησιμοποιεί τα φρένα.
Έχει σταματήσει να κάνει πετάλι.
Πηγαίνει ολοένα και πιο αργά.



Νομίζεις ότι η τριβή μειώνει την ταχύτητα του ποδηλάτου;

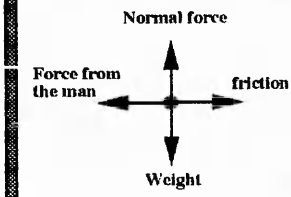
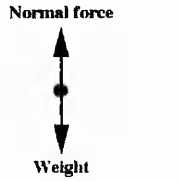
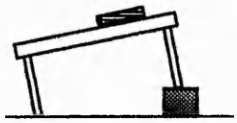
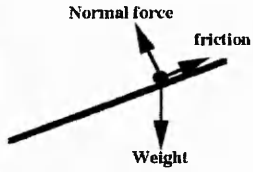
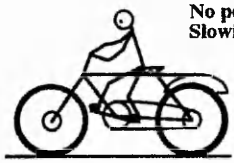
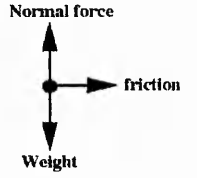
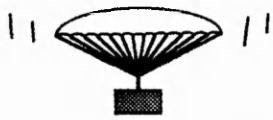
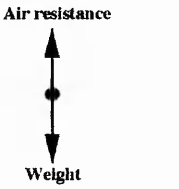
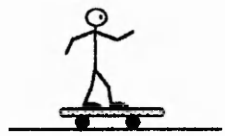
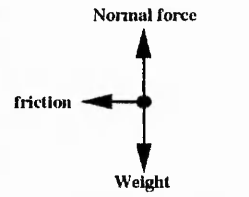
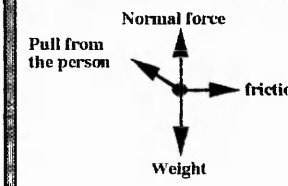
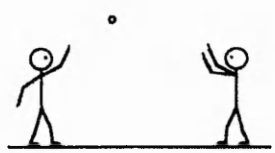
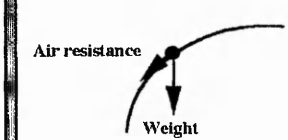


A. Γλιστράει αργά πάνω στην τσουλήθρα.
Νομίζεις ότι υπάρχει τριβή εδώ;

B. Κρατάει σταθερά με τα χέρια πάνω στην τσουλήθρα. Δε γλιστράει...
Νομίζεις ότι υπάρχει τριβή εδώ;

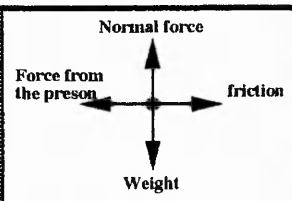
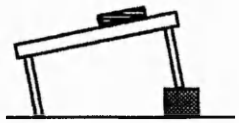
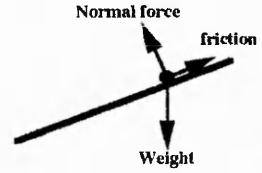
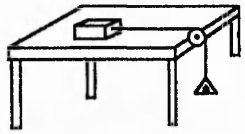
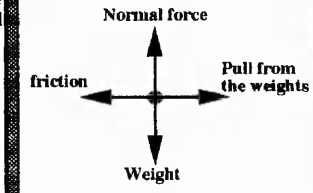
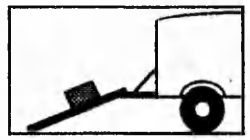
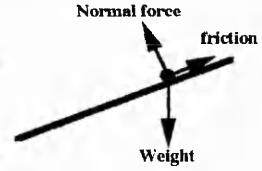
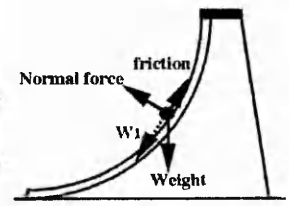
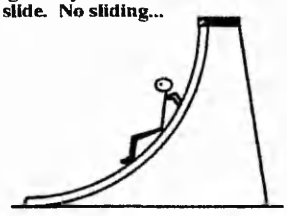
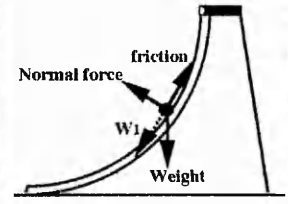
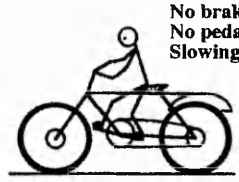
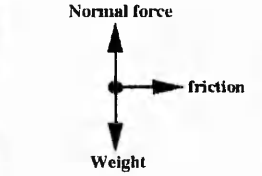
APPENDIX III

APPENDIX III: Analysis of the Pre-Intervention Interview Cards with Respective Comments

INTERVIEW CARD	VECTOR ANALYSIS	COMMENTS
The man is trying to move the car but the car is not moving. **Engine not going**  **Is there a force on the car?**		This is a free-body diagram of the car. If we consider the forces exerted on the car as a whole, they are the normal force N pushing outward from the horizontal plane of the ground, the weight W of the car, the force from the man F and the frictional force f pointing on the right, hindering the motion. If we consider the phenomenon at the local points of contact of the rubbing surfaces of the wheels and the ground, things are quite different. The **Net Force=0**, so the car is in equilibrium (stationary).
There is a book on the table.  **Do you think there are any forces here?**		This is a free-body diagram of the book on the table. The forces on the book are the normal force N pushing outward from the horizontal plane of the table and the weight W of the book. The **Net Force=0**, so the book is in equilibrium (stationary).
We lift the table a little bit from one of the sides The book does not slide down.  **Do you think there is any force keeping it there?**		This is a free-body diagram of the book on the tilted table. The forces on the book are the normal force N pushing outward from the tilted plane of the table, the weight W of the book and the frictional force f which points up the plain because the impedning motion is down the plane. The **Net Force=0**, so the book is in equilibrium (stationary).
No brakes **No pedaling** **Slowing down**  **Is there a force on the bike?**		This is a free-body diagram of the bicycle. If we consider the bicycle decelerating as a whole, the forces on it are the normal force N pushing outward from the horizontal plane of the ground, the weight W of the bicycle and the frictional force f from the air resistance pointing on the right opposing the motion. If we consider the phenomenon on the rubbing surfaces of the wheels and the ground, where static friction is present at the local interface of contact, things are quite different. **The bicycle is decelerating.** →
A box full of food and medicines was dropped with a parachute from an aeroplane. It goes down slowly.  **Do you think there are any forces here?**		This is a free-body diagram of the parachute and the box in the air. The forces are the air resistance Fa pushing upwards and the weight W of the box and the parachute pulling them both towards the earth. The **Net Force=0**, so the box and the parachute are falling with constant velocity.
Rolling with the skateboard. No pushing. Slowing down...  **Do you think there are any forces here?**		This is a free-body diagram of the skateboard. If we consider the skateboard decelerating as a whole, the forces on it are the normal force N pushing outward from the horizontal plane of the ground, the weight W of the skateboard and the frictional force f from the air resistance pointing on the left, opposing the motion. If we consider the phenomenon on the rubbing surfaces of the wheels and the ground, where static friction is present at the local interface of contact, things are quite different. **The skateboard is decelerating.** ←
Dragging a chair.  **Do you think there are any forces here?**		This is a free-body diagram of the chair. The forces are the the normal force N pushing outward from the horizontal plane of the ground, the weight W of the chair, the pull from the person Fp and the frictional force f pointing on the right opposing the motion. The **Net Force=0**, the chair is moving at constant velocity.
Throwing a tennis ball to the child over the other side.  **Do you think there are any forces here?**		This is a free-body diagram of the tennis ball. The forces on the tennis ball are the weight W pulling it towards the earth and the air resistance Fa which is tangential to the trajectory of the motion of the tennis ball. **The tennis ball is accelerating.** ↗

Two additional cards used for the interviews in Greece

APPENDIX III: Analysis of the Post-Intervention Interview Cards with Respective Comments

INTERVIEW CARD	VECTOR ANALYSIS	COMMENTS
Walking along the road.  **Is there any friction here?**		This is a free-body diagram of one of the shoes of the person walking at a constant velocity. The forces on the preson are the Normal force **N** pushing outward from the horisontal plane of the ground, the weight **W** of the person, the muscular force **Fp** pushing backwards in order to move forward and the friction **f** from the rubbing surfaces of the ground and the shoes pushing on the opposite direction of **Fp**. The **Net Force=0**, the person is moving at constant velocity
We lift the table up a little bit from one of the sides. The book does not slide down.  **Do you think friction is keeping it there?**		This is a free-body diagram of the book on the tilted table. The forces on the book are the normal force **N** pushing outward from the tilted plane of the table, the weight **W** of the book and the frictional force **f** which points up the plane because the impedning motion is down the plane. The **Net Force=0**, so the book is in equilibrium (stationary).
There is some weight in the tray, which is under the pulley at the end of the string. But the block of wood does not slide on the table.  **Do you think friction keeps it there?**		This a free-body diagram of the block of wood. The forces on the block of wood are the normal force **N** pushing outward from the horizontal plane of the table, the weight **W** of the block, the force from the weights in the tray **Fw** pulling the block on the right end the frictional force **f** pulling the block on the opposite direction hindering its motion. The **Net Force=0**, the block is in equilibrium (stationary)
There is a box left on a slope at the back of a truck. It is not sliding down...  **Do you think there is any friction here?**		This is a free-body diagram of the box on the slope. The forces on the box are the normal force **N** pushing outward from the tilted plane of the sloping board, the weight **W** of the box and the frictional force **f** which points up the plane because the impending motion is down the plane. The **Net Force=0**, so the book is in equilibrium (stationary).
Coming slowly down the slide.  **Do you think there is any friction here?**		This is a free-body diagram of the person on the slide. The forces on the person are the normal force **N** pushing outward from the tilted plane of the slide, the weight **W** of the person and the frictional force **f** which points up the side because the motion is down the slide. The tangential component of the weight **W1** is bigger than the frictional force **f**. **The person is accelerating** ↙
Holding steady with the hands on the sides of the slide. No sliding...  **Do you think there is any friction here?**		This is a free-body diagram of the person on the slide. The forces on the person are the normal force **N** pushing outward from the tilted plane of the slide, the weight **W** of the person and the frictional force **f** which points up the side because the motion is down the slide. The tangential component of the weight **W1** is equal and opposite to the frictional force **f**. The **Net Force=0**, the person is in equilibrium. (stationary)
No brakes **No pedalling** **Slowing down**  **Do you think friction slows down the bike?**		This is a free-body diagram of the bicycle. If we consider the bicycle decelerating as a whole, the forces on it are the normal force **N** pushing outward from the horizontal plane of the ground, the weight **W** of the bicycle and the frictional force **f** from the air resistance pointing on the right opposing the motion. If we consider the phenomenon on the rubbing surfaces of the wheels and the ground, where static friction is present at the local interface of contact, things are quite different. **The bicycle is decelerating.** →

APPENDIX IV

A_5. Style, notation and format of the interview transcripts

Some transcribing conventions have been adopted concerning the *style* and *notation* of the transcripts (Gilbert, Watts & Osborne, 1985, p. 18). The transcript is not punctuated or divided into sentences. Full stops, commas and the like are omitted. Question marks are also omitted, since "*the verbal inflective associated with questioning is sometimes used to make statements, the truth of which is uncertain to the speaker*" (ibid.). The pauses are also typed and sounds like laughter and cough are included in the transcript (see table A_5.1).

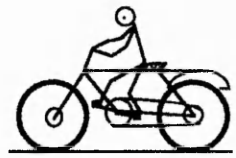
The format of the transcripts is in tables of three columns. The utterance numbers, an abbreviation of the word interviewer (**Int.**) and the first two letters of the name of the interviewee (i.e. **An**) are included in the first column on the left. The utterance numbers can be either whole numbers, when there is no interruption by one of the speakers, or a decimal number when there is an interruption, contradiction or overlap. In the second column the main body of the interview transcript is typed using the notation code. A reduced version of the interview cards and some comments concerning equivalent utterances of the interview are included in the third column (cf. Appendix VI that follows).

Parentheses: ( )	They enclose unavoidable interpretations and they are put within the utterance that they apply.
Square brackets: [ ]	They enclose information and comments and they are placed on the third column, on the right hand side of the page.
Transcriber's doubt: **	Asterisks show the transcriber's doubts, mainly due to the acoustics of the tape. they are include within the utterance with as much of the sound as possible. The number of asterisks roughly indicates the number of words.
Periods:	They indicate pauses. One period indicates a very short pause, thereafter the number of periods indicate the length of the pause.
Number of seconds: **..6..**	For longer pauses, the number of seconds is roughly indicated by a numeral preceded and followed by two periods.
A prolonged or drawn out sound: **fo::ce**	A prolonged or drawn out sound within a word is indicated by a number of columns included in the word.
Stressed syllables: **fric**tion	Stressed syllables are indicated by using bold characters.
Overlapping utterances: >>	Two symbols of "bigger than" (>>) indicated overlapping utterances or instances where one speaker cut into the other.
Rising tone: /	This symbol indicated a rising inflection, not necessarily leading to a question.
Falling tone: \	This symbol indicated a falling inflection usually when the voice of the speakers dies out for some reason.
umm hmm umm er	These sounds are also included wherever appropriate.
(laugh) (cough) (snort)	This is how laughter, cough, snort etc. are included in the transcripts.

Table A_5.1: The code of notation used for the interview transcripts

APPENDIX V

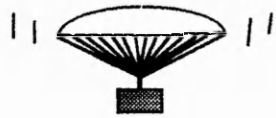
Pre-Intervention Interview (Da)



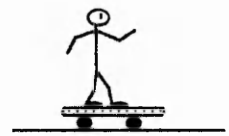
001 **Int** hello (Da) ... I think we are ready to start with this card ... you can take a look at the drawing.. read the sentences and ... then we can have a chat abut it ...
002 **Da** no brakes .. no pedalling .. slowing down .. is there a force on the bike.. /
003 **Int** umm hmm.. what do you think .. /
004 **Da** umm ..4..
005 **Int** do you think there are any forces on the bike .. /
006 **Da** yeah... 'cos it's like .. the man is on it.. the force is going down to the wheels which are pressed on the ground ...
007 **Int** yeah ..
008 **Da** it's actually gravity .. the man's weight pushing the bike to the ground ...
009 **Int** yes.. but the bike is slowing down ... you see the rider is not pedalling .. not using the brakes either.. but the bike slows down and eventually it stops .. why do you think that happens .. /
010 **Da** well .. it's like .. the gravity is like .. pulls it down .. it's trying to stop it and it's like the force of the weight of the man .. is pushing the bike along ...
011 **Int** yeah ..
012 **Da** then is.. it's like pulling against the force of gravity which is like ..\ .. that's why it slows down..
013 **Int** yeah ...do you feel there are any forces at the touching points of the ground .. /
014 **Da** yeah ..4..
015 **Int** what do you mean .. /
016 **Da** well .. there must be forces but .. I don't know if that's stopping the bike .. it's just the weight actually pulling it down ..
017 **Int** any other forces here.. /
018 **Da** umm.. the wind .. if it.. if it is blowing behind of him it'll speed him up a little bit.. and if it's blowing this way.. it'll slow down faster 'cos it's pushing him back ...

[pointing at the opposite direction. behind the rider]

019 **Int** anything else to add on this one .. /
020 **Da** no..
021 **Int** O.K. .. let's take a look at the next card then ..
022 **Da** a box full of food and medicines was dropped with a parachute from an aeroplane .. it goes down slowly.. do you think there are any forces here .. /



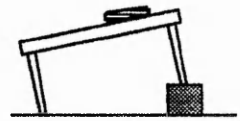
023 **Int** yeah.. what do you think .. /
024 **Da** umm..4.. it's like .. well the wind is like .. it's being hold inside the parachute .. it's like pushing up against the parachute ..
025 **Int** umm hmm ..
026 **Da** so.. it's like .. er.. slowing it down 'cos .. 'cos it's .. with the parachute and the box ... just the box on its own wouldn't.. it wouldn't have as much air to push it up away .. 'cos it's like holding in the air..
027 **Int** yeah..
028 **Da** .. and it's like .. so it's the air that can't get out of it .. which like holds it up..
029 **Int** holds it up .. do you mean the parachute .. /
030 **Da** yeah ..
031 **Int** all right .. do you think there are any other forces here .. /
032 **Da** umm .. gravity .. it's just like pulling everything down .. you know..
033 **Int** yeah .. anything else .. /
034 **Da** no .. just that ...
035 **Int** O.K. .. let's take a look at the next one then..
036 **Da** rolling with the skateboard .. no pushing .. slowing down .. do you think there are any forces here .. /.. umm ... is it on a flat ground .. /



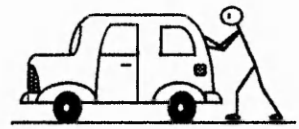
037 **Int** yeah.. we can suppose so ..
038 **Da** er.. he is not pushing.. umm .. well it's basically same as the bike really 'cos ..
038.5 **Int** >> yeah..
039 **Da** .. er.. gravity is like pulling it down so.. which is stopping it ..
040 **Int** umm hmm.. do you think there are any forces at the touching points of the wheels and the ground.. /
041 **Da** no .. I don't think so...
042 **Int** anything else you would like to add here.../
043 **Da** well it's the wind .. it depends where it is blowing from ... if the wind is blowing behind him ... it's like pushing him along .. same with the bike ..
044 **Int** yeah ..
045 **Da** .. but I think that eventually it will stop ..
046 **Int** umm hmm... any idea why that will happen .. /
047 **Da** er.. no I can't really explain this ..
048 **Int** O.K. .. let's see the next card then ...



049 **Da** there is a book on the table ... do you think there are any forces here ... / .. same again ... it's gravity which is pulling it ..
050 **Int** umm hmm ..
051 **Da** er..4..
052 **Int** why do you think the book stays on the table .. /
053 **Da** umm.. it's because of gravity.. and if there weren't the table the book would fall straight down ...
054 **Int** yeah .. I see ..
055 **Da** a bit like .. it can't really go through the table .. 'cos the table is like a solid thing and the book can't pass through the table .. *(laugh)*
056 **Int** yeah .. all right .. do you think there is any force from the table towards the book .. /
057 **Da** er.. no I don't think so ..
058 **Int** O.K. .. let's see the following card then ..



059 **Da** we lift the table up a little bit from one of the sides .. the book does not slide down.. do you think there is any force keeping it there .. /.. umm ..6..
060 **Int** yeah... well .. have you got experience of such a situation .. /
061 **Da** yeah .. I've tried that before .. at home ..
062 **Int** all right .. what do you think is keeping the book there .. /
063 **Da** umm.. the wind could be pushing it up ... er.. but there's not much wind in the room ...*(laugh)*
064 **Int** well .. yes I would think so as well .. *(laugh)*.. anything else apart from that.. / .. can you recognise any other forces here... /
065 **Da** umm.. in that position .. it will be gravity pulling it down off the table .. I mean down .. /
066 **Int** umm hmm ..
067 **Da** is it just a free book or is it glued or anything .. /
068 **Int** no.. it's just a book and it's not glued or anything ...
069 **Da** well .. I don't know it stays there .. I reckon ...
070 **Int** yeah ..
071 **Da** er.. I think gravity would actually pull it along the table and down .. but this does not happen ...
072 **Int** do you think there are any forces there ... where the surface of the cover of the book is touching the surface of the table .. / [pointing at the equivalent spot at the picture]
073 **Da** well. .. yeah.. it's touching .. ain't it... it's like ... are there any grips or anything on the book .. /
074 **Int** what do you mean .. /
075 **Da** well you know.. books can have like .. ripply covers.. can't they.. /
076 **Int** yeah .. do you think that could hold the book on the table.. /
077 **Da** er.. it might do.. it depends on the substances.. 'cos I know .. like rubber can hold things.. but if it was plastic or like.. like .. it would roll down ..
078 **Int** do you think the surface of the table has anything got to do with it .. /
079 **Da** yeah .. because like .. as I say.. it's different substances.. this is like .. making roll off a lot easier.. or.. just hold it back there ..
080 **Int** oh .. I see anything else you would like to add on this one .. /
081 **Da** no..



082 **Int** O.K. .. let's see the last card then ..
083 **Da** the man is trying to move the car but the car is not moving .. engine not going .. is there a force on the car.. /.. umm ..4..
084 **Int** yeah.. what do you think .. /
085 **Da** well .. it's the man actually with his strength pushing the car .. that's one force..
086 **Int** yeah.. but the car is not moving ..
087 **Da** well.. the wheels are like .. been held down onto the ground ..
088 **Int** how do you think that happens .. /
089 **Da** er..4.. with gravity ..
090 **Int** in what way do you think gravity holds the wheels down onto the ground .. /
091 **Da** in what way.. /.. 'cos it's like a big Hoover that sucks everything down onto the ground ..
092 **Int** all right .. I see .. do you think there are any forces at the touching points of the wheels and the ground .. /
093 **Da** well as I said before.. it's like the .. the different substances.. 'cos it's rubber wheels.. and it's like sort of .. well.. it's like jammed ..
094 **Int** umm hmm ..
095 **Da** and if it is like a rough ground.. it holds the wheels in place ..
096 **Int** what do you mean .. /
097 **Da** they would get more into it .. they would grip more ...
098 **Int** yeah .. anything else you would like to add here .. /
099 **Da** it would be different if you put some sort of oil there .. and there .. [pointing under the wheels]
100 **Int** yeah .. what would happen then .. /

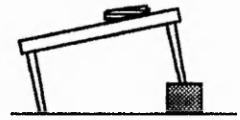
101	**Da**	it would move easier .. you see.. he would push the same but the car .. it would move then ..
102	**Int**	why do you think that would happen .. /
103	**Da**	'cos oil is like slippery .. it lets the car slip on the ground .. on the slippery surface .. I mean..
104	**Int**	all right ... I see.. any other forces in this situation .. /
105	**Da**	no .. I can't really see any other forces .. \ no..
106	**Int**	O.K. .. thank you very much (Da) .. I think we have finished ..
107	**Int**	that's all right .. you 're welcome...

Post-Intervention Interview (Da)

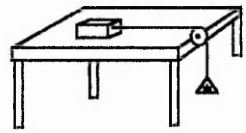
001 **Int** hello (Da) ...
002 **Da** hello .. are you all right .. /
003 **Int** yes .. I am fine thanks .. well (Da) .. I've got another set of cards here .. you can take a look at the drawings .. read the sentences that describe them and then we can have a chat about it .. is that all right .. /
004 **Da** yeah .. that's fine ..
005 **Int** let's start with the first card then ..



006 **Da** walking along the road .. is there any friction here .. /.. yeah .. there's a little bit of friction .. it would be more friction if you're dragging your feet on the ground .. 'cos they rub more you see ..
007 **Int** yeah .. but what happens when you don't drag your feet .. / .. when you just walk normally .. /
008 **Da** well there's not really much contact in this case .. or there is some but not much .. there is just a little bit of friction created .. to keep you going I suppose ..
009 **Int** what happens when you are dragging your feet on the ground then .. /
010 **Da** er .. when you are dragging your feet they hardly get of the ground .. so they really rub more and that creates friction .. that's why .. when I am dragging my feet .. it makes it a lot more difficult to walk ..
011 **Int** yeah .. anything else you would like to add here .. /
012 **Da** well .. it's also the force of gravity that is pulling the person down .. sort of sticking him on the road ..
013 **Int** I see .. anything else .. /
014 **Da** no ..
015 **Int** let's take a look at the next card then ..



016 **Da** we lift the table up a little bit from one of the sides .. the book does not side down .. do you think friction is keeping it there .. / yeah .. it depends on the surfaces ..
017 **Int** yeah .. what do you mean .. /
018 **Da** say if the table surface is rough .. and the cover of the book is also rough .. then .. they're kind of sticking together .. the roughness does that .. but say .. if it was smooth and .. say the book was made of plastic .. then it wouldn't grip as much .. so it would slide down ..
019 **Int** I see .. how do you think that .. the roughness of the book keeps it there .. /
020 **Da** well .. it's hard to explain that .. first there's gravity holding it onto the table .. and then .. if the table is a bit rough .. it will have all these little things there .. and the book would grip on it .. that would create some friction that would help the book stay still ..
021 **Int** so .. how many forces do you think that keep the book there .. /
022 **Da** it's two .. gravity that kind of sticks it onto the table .. and friction that holds it back .. er..4.. also it depends how high the table is ..
023 **Int** what do you mean .. /
024 **Da** well .. the highest the table is .. the less friction is there .. 'cos then gravity is pulling it *(the book)* more down .. and so it slides ..
025 **Int** why do you think that gravity is pulling the book more down .. if we lift the table a bit higher .. /
026 **Da** 'cos it's getting higher off the ground .. so it *(the book)* wants to go down immediately.. I suppose ..
027 **Int** all right .. I see .. anything else you would like to add here .. /
028 **Da** no ..
029 **Int** let's see the next card then ..



030 **Da** there is some weight in the tray .. which is under the pulley at the end of the string .. but the block of wood does not slide on the table .. do you think friction keeps it there .. / .. yeah .. that looks exactly like the investigation we did last week .. only there's no sandpaper here .. 'cos my group had sandpaper on the table ..
031 **Int** yes .. I remember that .. but can you describe what you think that is happening here .. /
032 **Da** well .. say if this is a wooden table .. and you have that piece of wood on it like that .. and it doesn't slide along the table .. well .. two things are happening then ... er..4.. [pointing at the card]
033 **Int** umm hmm .. what do you mean .. /
034 **Da** well .. it's either that friction is created on the rough surfaces of the wood and the table .. or .. there's not enough weight to pull it along.. er .. or it could be both actually *(laugh)* ..
035 **Int** what do you suggest then .. /

036 **Da** well .. there's definitely some friction .. 'cos the surfaces there are rough .. and all these bits and pieces get into each other .. and that sort of resists the weight that is pulling the wood .. 'cos it's not enough .. I reckon ..

037 **Int** all right .. anything else you would like to add here ..

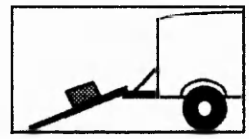
038 **Da** well .. it would be different on sandpaper ..

039 **Int** what would be the difference .. /

040 **Da** you need a lot more weight .. to start it sliding .. 'cos the surface of the table is a lot rougher .. so .. you might need nearly as much weight as the piece of wood .. that's what our group found out ..

041 **Int** yeah .. I remember that's what you found out .. thank you .. let's take a look at the next card then ..

042 **Da** there's a box left on a slope at the back of a truck .. it is not sliding down .. do you think there is any friction here .. / ..yeah .. this is very similar to the table and the book .. kind of thing .. so there's some friction here .. but also gravity..



043 **Int** what do you mean .. / .. could you describe that a bit .. please .. /

044 **Da** well .. all the points of contact those little tops and valleys .. inter.. er .. interlock with the slope .. that means they get into one another .. kind of thing .. and that holds the box there .. and also because of gravity ..

045 **Int** what happens with gravity then .. /

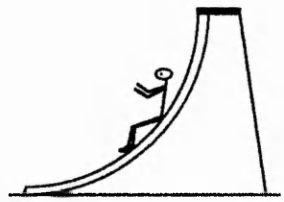
046 **Da** er .. it pulls that box down .. but it kind of sticks it on the slope .. 'cos that's in the way .. you see .. so it helps it grip more ..

047 **Int** yeah .. I see .. anything else you would like to add here .. /

048 **Da** no .. that's all .. friction and gravity are just keeping the box there ..

049 **Int** all right .. let's take a look at the next card then .. can we go through A first and then B please .. /

050 **Da** yeah .. A .. coming slowly down the slide .. do you think there is any friction here .. / .. yeah .. there is friction here .. 'cos as he is sliding down .. he is rubbing his jeans and his shoes on the slide .. that creates friction and slows him down a little bit ..



051 **Int** how do you think that rubbing creates friction here .. /

052 **Da** well you know .. rubbing .. just like when you rub your hands .. they grip .. cause they sort of catch on each other .. I suppose .. that's why you get a bit of dirt in your hands after that ..

052.5 **Int** >> umm hmm .. I see ..

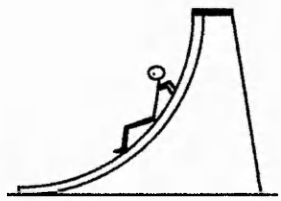
053 **Da** .. and what happens here is that his buttocks are rubbing on the surface of the slide .. and say if that *(the slide)* was a longer one .. he would feel like burning soon .. 'cos he will get hot from all that rubbing *(laugh)*..

054 **Int** all right *(laugh)* .. why do you think that he would get hot then .. /

055 **Da** well his buttocks would get hot .. just like your hands when you rub them .. I don't know really .. it just happens ..

056 **Int** all right .. let's take a look at B situation then ..

057 **Da** holding steady with the hands at the sides of the slide .. do you think there is any friction here .. / .. yeah .. 'cos you see .. his hands are like gripping at the sides of the slide .. and he also puts a lot of power with his fingers to hold himself right there ..



058 **Int** how do you think that his hands are gripping at the sides of the slide .. /

059 **Da** well .. he is forcing them to grip .. by putting a lot of power on them .. to hold really steady .. that creates a lot of friction ..

060 **Int** I see .. in which case do you think there is more friction .. / .. in A or in B .. /

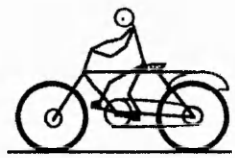
061 **Da** in B .. 'cos there are more points of contact .. and he is staying up there steady .. so there are more places for friction .. to go .. that's it ..

062 **Int** all right .. anything else you would like to add here .. /

063 **Da** no .. not really ..

064 **Int** let's take a look at the last card then ..

065 **Da** no brakes .. no pedalling.. slowing down .. do you think friction slows down the bike .. / .. well yeah .. friction on the tyres .. that slows it down ..



066 **Int** can you describe how do you think that happens .. /

067 **Da** well .. the road is bumpy you see .. 'cos it's always an uneven surface .. and the tyres .. they are sort of rough .. and they have kind of crannies .. that grip on the bumps of the road .. and slow down the bike .. and eventually stop it .. er ..4.. it's also the material of the tyres .. 'cos they are made of rubber you see..

068 **Int** why do you say that about rubber .. /

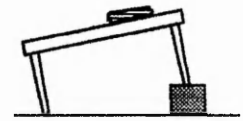
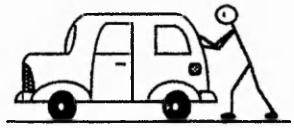
069 **Da** well .. rubber is rather sticky .. I suppose .. that would increase friction wouldn't it .. / .. 'cos it will be gripping a lot more .. than say wood or something like that ..

070 **Int** yeah .. I see .. anything else you would like to add here .. /

071 **Da** umm .. there's some more friction there .. at his hands that are gripping on the handlebars.. er..4.. [pointing at the handlebars]

072	**Int**	yeah .. anything else .. you have in mind .. /	
073	**Da**	there is also some more friction .. there .. under his shoes that are gripping on the pedals .. and also at the saddle where he is sitting .. that's about it ..	[pointing at the pedals]
074	**Int**	all right .. I think we have finished now .. thank you very much (Da)	
075	**Da**	that's all right .. you're welcome ..	

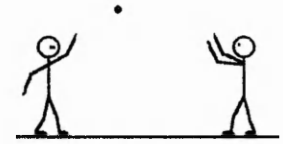
Pre-Intervention Interview (Δη) or (Di)

001	**Ερευ**	γειά σου (Δη) .. τι κάνεις .. /	
002	**Δη**	καλά..	
003	**Ερευ**	λοιπόν (Δη) εδώ έχω μερικές κάρτες.. οι οποίες περιέχουν κάποιες εικόνες... μπορείς να κοιτάξεις τις εικόνες .. να διαβάσεις τις προτάσεις που τις περιγράφουν και μετά θα συζητήσουμε λίγο πάνω σ' αυτές.. εντάξει.. /	
004	**Δη**	ναι ...	
005	**Ερευ**	ας αρχίσουμε με την πρώτη κάρτα...	
006	**Δη**	υπάρχει ένα βιβλίο πάνω στο τραπέζι.. νομίζεις ότι υπάρχουν δυνάμεις εδώ.. /.. ναι.. υπάρχουν..	
007	**Ερευ**	ποιές δυνάμεις νομίζεις ότι είναι αυτές .. /	
008	**Δη**	εε.. το βιβλίο όταν είναι πάνω στο τραπέζι έχει κάποιο βάρος.. εε .. και το τραπέζι που είναι πάνω στη γη .. έχει και αυτό κάποιο βάρος..	
009	**Ερευ**	μάλστα.. νομίζεις ότι υπάρχει καμία δύναμη από το τραπέζι προς το βιβλίο.. /	
010	**Δη**	εε.. το βιβλίο με το βάρος του παραμένει πάνω στο τραπέζι.. και::...έτσι το βιβλίο έχει τη δράση και το τραπέζι που το στηρίζει έχει την αντίδραση..	
011	**Ερευ**	μμ χμμ.. νομίζεις ότι υπάρχουν δυνάμεις εκεί που τα πόδια του τραπεζιού ακουμπούν στο έδαφος.. /	
012	**Δη**	ναι .. το τραπέζι με το βάρος του ασκεί τη δράση .. και η γη που το στηρίζει ασκεί μια αντίδραση..	
013	**Ερευ**	αυτές είναι διαφορετικές δυνάμεις.. /	
014	**Δη**	ναι...	
015	**Ερευ**	άλλες δυνάμεις νομίζεις ότι υπάρχουν εδώ.. /	
016	**Δη**	μμ..4.. όχι..δεν υπάρχουν άλλες δυνάμεις..	
017	**Ερευ**	ας δούμε τότε την επόμενη κάρτα..	
018	**Δη**	σηκώνουμε λίγο το τραπέζι από τη μια μεριά το βιβλίο δε τσουλάει προς τα κάτω.. νομίζεις ότι υπάρχει κάποια δύναμη που το κρατάει εκεί.. / .. εε.. ναι..	
019	**Ερευ**	τι εννοείς .. /	
020	**Δη**	γιατί για να πέσει το βιβλίο πρέπει να .. εε.. πρέπει να το σηκώσουμε πιο πολύ..	
021	**Ερευ**	μμ χμμ.. γιατί νομίζεις ότι πρέπει να το κάνουμε έτσι.. /	
022	**Δη**	γιατί:: .. και πάλι εδώ πέρα .. όπως είναι δε μπορεί να τσουρλήσει.. γιατί:: ... κάτι πρέπει να το κρατάει..	
023	**Ερευ**	τι νομίζεις ότι μπορεί να είναι αυτό.. /	
024	**Δη**	εε.. το τραπέζι..	
025	**Ερευ**	πώς νομίζεις ότι το τραπέζι κρατάει το βιβλίο ακίνητο στη θέση του.. /	
026	**Δη**	εε.. εξαρτάται από τι είναι φτιαγμένο.. εε.. από ξύλο.. μμ.. αν το τραπέζι είναι ξύλινο τότε .. κάπως το βιβλίο .. γαντζώνεται απάνω του..και κρατιέται.. εε .. ενώ εάν είναι από.. έχει φορμάϊκα εδώ πάνω.. τότε μπορεί και να γλιστρήσει.. ακόμα και χωρίς να το σηκώσουμε πολύ..	[δείχνει πάνω στην επιφάνεια του τραπεζιού]
027	**Ερευ**	μάλιστα .. άλλες δυνάμεις νομίζεις ότι υπάρχουν εδώ../	
028	**Δη**	μμ. ναι το βάρος του βιβλίου .. και το βάρος του τραπεζιού..	
029	**Ερευ**	άλλο τίποτε έχεις να προσθέσεις εδώ../	
030	**Δη**	μμ.. α.. ναι.. εδώ .. το βάρος του τραπεζιού έχει δράση και το κουτί ασκεί μια αντίδραση.. το ίδιο και εδώ με το έδαφος.. μμ .. και με το βιβλίο και το τραπέζι.. μμ .. αυτά..	[δείχνει εκεί που το ένα πόδι του τραπεζιού ακουμπάει πάνω στο κουτί]
031	**Ερευ**	ας δούμε και την επόμενη κάρτα ..	
032	**Δη**	προσπαθεί να μετακινήσει το αυτοκίνητο αλλά αυτό δε μετακινείται.. ο κινητήρας δε λειτουργεί.. νομίζεις ότι ασκούνται δυνάμεις στο αυτοκίνητο.. / .. ναι ασκούνται..	
033	**Ερευ**	ποιές δυνάμεις νομίζεις ότι είναι αυτές.. /	
034	**Δη**	είναι η δύναμη που του δίνει ο άνθρωπος.. μμ..4..	
035	**Ερευ**	γιατί νομίζεις ότι το αυτοκίνητο δε μετακινείται.. /	
036	**Δη**	εε.. γιατί ο άνθρωπος το σπρώχνει με τις δινάμεις του .. αλλά αυτό έχει πολύ μεγαλύτερο βάρος από τον άνθρωπο.. και έτσι δυσκολεύεται να το μετακινήσει μόνος του.. μάλλον θα χρειαστεί κι άλλους ανθρώπους για βοήθεια..	
037	**Ερευ**	μάλιστα.. άλλες δυνάμεις νομίζεις ότι υπάρχουν εδώ../	
038	**Δη**	μμ.. ναι .. ειναι το βάρος του ανθρώπου .. και το βάρος του αυτοκινήτου που είπα πριν.. εε..	
039	**Ερευ**	νομίζεις ότι υπάρχουν δινάμεις στα σημεία όπου οι ρόδες του αυτοκινήτου ακουμπούν πάνω στο έδαφος../	
040	**Δη**	ναι .. γιατί εκεί στις ρόδες .. και στα παπούτσια του ανθρώπου .. ασκείται η δράση .. εε.. από το βάρος .. και από τη γη ασκείται μια αντίδραση..	[δείχνει στις ρόδες και στα παπούτσια]

041 **Ερευ** μάλιστα .. τίποτε άλλο έχεις να προσθέσεις εδώ../

042 **Δη** όχι ..

043 **Ερευ** καλά.. ας δούμε και την επόμενη κάρτα..



044 **Δη** πετάει το μπαλάκι στο παιδί που βρίσκεται απέναντι.. νομίζεις ότι ασκούνται δυνάμεις στο μπαλάκι.. / .. ναι ..

045 **Ερευ** ποιές δυνάμεις νομίζεις ότι ασκούνται .. /

046 **Δη** γιατί το παιδί.. δίνει στο μπαλάκι μια δύναμη να πάει στο άλλο παιδί.. και το αντίθετο... μετά πάλι.. εε..

047 **Ερευ** μάλιστα.. νομίζεις ότι ασκούνται άλλες δυνάμεις στο μπαλάκι όταν αυτό βρίσκεται στον αέρα.. /

048 **Δη** μμ.. ναι έχει βάρος.. αλλά με τη δύναμη που του δίνει το παιδί πηγαίνει απέναντι .. και δεν πέφτει προς τα κάτω..

049 **Ερευ** άλλες δυνάμεις νομίζεις ότι υπάρχουν εδώ.. /

050 **Δη** ναι .. είναι και το βάρος των παιδιών .. που πέφτει στα πόδια τους.. που είναι μια δράση .. και το έδαφος που ασκεί .. ασκεί μια αντίδραση σ' αυτό το βάρος..

051 **Ερευ** μπορείς να εξηγήσεις τι εννοείς όταν λες δράση../

052 **Δη** εε.. τα παιδια με τα παπουτσια τους .. μμ.. τα πόδια τους.. ας πούμε .. δηλαδή με το βάρος τους δεν μπορούνε να φύγουνε..

053 **Ερευ** τί εννοείς δηλαδή.. /

054 **Δη** το παιδί με τα πόδια του .. δηλαδή φοράει τα παπούτσια και δε μπορεί να γλιστρήσει .. και η γη το κρατάει με το βάρος του .. που έχει..

055 **Ερευ** νομίζεις ότι υπάρχει καμία σχέση ανάμεσα στη δράση και στο βάρος .. / .. όπως τα εννοείς εσύ εδώ.. /

056 **Δη** όχι..

057 **Ερευ** είναι δηλαδή δύο διαφορετικά πράγματα.. /

058 **Δη** ναι.. γιατί το παιδί δεν περπατάει .. ας πούμε.. δηλαδή δε σπρώχνει με τα πόδια του με δύναμη κάτω για να κουνηθεί .. εε .. να μετακινηθεί..

059 **Ερευ** και αυτό έχει να κάνει με το βάρος ή με τη δράση .. / .. που λες..

060 **Δη** με τη δράση.. με τη δύναμη που το κάνει να μπορεί να μετακινείται .. ενώ το βάρος... ασκείται όταν δεν κινείται..

061 **Ερευ** μάλιστα.. άλλο τίποτε έχεις να προσθέσεις εδώ.. /

062 **Δη** όχι..

063 **Ερευ** ας δούμε τότε την επόμενη κάρτα..



064 **Δη** τραβάει το καρεκλάκι.. νομίζεις ότι ασκούνται δυνάμεις εδώ.. / .. ναι..

065 **Ερευ** ποιές δυνάμεις νομίζεις ότι ασκούνται.. /

066 **Δη** με τα πόδια του .. έχει δράση και η γη έχει αντίδραση.. γιατί εδώ προχωράει.. εε.. επίσης .. το παιδί ασκεί μία δύναμη και με το χέρι του.. που τραβάει το καρεκλάκι... αλλά .. και το καρεκλάκι .. πάλι το πόδι του έχει δράση και η γη έχει αντίδραση .. γιατί και αυτό πάλι μετακινείται..

067 **Ερευ** εκεί όπου το παιδί τραβάει το καρεκλάκι .. ποιά δυναμη νομίζεις ότι υπάρχει.. /

068 **Δη** μμ.. η δράση .. ναι γιατί το βοηθάει να κουνηθεί..

069 **Ερευ** μάλιστα.. πότε νομίζεις ότι θα ασκήσει μικρότερη δύναμη το παιδί για να μεταφέρει το καρεκλάκι.. τώρα που το τραβάει ή όταν το σηκώσει.. /

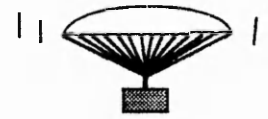
070 **Δη** εε.. τώρα που το τραβάει.. γιατί όταν θα το σηκώσει .. θα σηκώσει ολόκληρο το βάρος του και άρα θα πρέπει να ασκήσει μεγαλύτερη δύναμη.. ενώ τώρα ασκεί αντίδραση η γη στο βάρος του και έτσι βοηθάει το παιδί..

071 **Ερευ** μάλιστα .. άλλες δυνάμεις νομίζεις ότι υπάρχουν εδώ.. /

072 **Δη** ναι.. είναι το βάρος του παιδιού.. εε.. και το βάρος από το καρεκλάκι.. και όπως προχωράνε ασκείται μια αντίδραση από τη γη.. εε.. αυτά..

073 **Ερευ** καλά .. ας δούμε και τη επόμενη κάρτα..

074 **Δη** ένα κουτί γεμάτο με τροφές και φάρμακα πέφτει με αλεξίπτωτο από ένα αεροπλάνο.. κατευθύνεται αργά προς το έδαφος ... νομίζεις ότι υπάρχουν δυνάμεις εδώ.. / .. ναι..



075 **Ερευ** ποιές δυνάμεις νομίζεις ότι υπάρχουν εδώ..

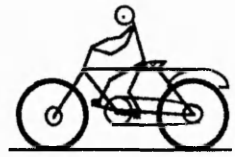
076 **Δη** εε .. είναι το βάρος του κουτιού... και η δύναμη που έχει το αλεξίπτωτο επειδή κρατάει τον αέρα μέσα του.. και έτσι το κουτί δεν πέφτει κατευθείαν κάτω..

077 **Ερευ** τί εννοείς.. / .. πως δηλαδή .. κρατάει τον αέρα το αλεξίπτωτο.. /

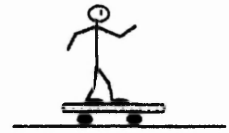
078 **Δη** εε.. έτσι που πέφτει ο αέρας μπαίνει μέσα στο αλεξίπτωτο .. και σα να το σπρώχνει προς τα πάνω .. και έτσι το κρατάει στο αέρα .. και έτσι αυτό κατευθύνεται αργά προς το έδαφος .. εε.. δηλαδή κρατάει τον αέρα μέσα του έτσι που πέφτει και δεν πέφτει απότομα .. με μεγάλη δύναμη..

079 **Ερευ** μάλιστα.. άλλες δυνάμεις νομίζεις ότι υπάρχουν εδώ../

080 **Δη** μμ..4.. ναι .. εκεί στα σχοινιά.. είναι σα ... μμ .. το κουτί με το βάρος του έχει μια δράση και το αλεξίπτωτο... σα να το τραβάει αντίθετα.. και έτσι έχει μια αντίδραση..

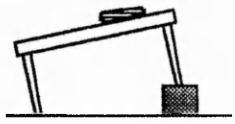


081 **Ερευ** μμ χμμ.. άλλο τίποτε έχεις να προσθέσεις εδώ../
082 **Δη** όχι...
083 **Ερευ** ας δούμε τότε την επόμενη κάρτα ...
084 **Δη** δε χρησιμοποιεί τα φρένα .. έχει σταματήσει να κάνει πετάλι... πηγαίνει ολοένα και πιο αργά ... ασκείται καμία δύναμη στο ποδήλατο.. ./ .. ναι ασκούνται κάποιες δυνάμεις..
085 **Ερευ** ποιές δυνάμεις νομίζεις ότι είναι αυτές.. /
086 **Δη** εε.. εκεί που ακουμπάνε οι ρόδες στο έδαφος έχουν μια δράση ...με το βάρος του ποδηλάτου ασκούν τη δράση .. και η γη ασκεί μια αντίδραση.. επίσης στη σέλα του ποδηλάτου.. το παιδί με το βάρος του ασκεί μια δράση και η σέλα ασκεί μια αντίδραση..
087 **Ερευ** τι εννοείς όταν λες ότι.. οι ρόδες του ποδηλάτου ασκούν μια δράση .. /
088 **Δη** εε.. οι ρόδες έχουν δράση γιατί πάνε να μετακινηθούν ... ενώ η γη δεν τις αφήνει..
089 **Ερευ** πώς δεν τις αφήνει η γη.. /
090 **Δη** εε.. ή .. ο ποδηλάτης δεν κάνει τις ρόδες να κινηθούν γιατί δεν πατάει πετάλι ..
091 **Ερευ** μάλιστα... το ποδήλατο εδώ.. πηγαίνει ολοένα και πιο αργά .. και κάποια στιγμή θα σταματήσει .. γιατί νομίζεις ότι θα συμβεί αυτό .. /
092 **Δη** γιατί το παιδί έχει σταματήσει να κάνει πετάλι.. εε.. και αφού δεν πιάνει και φρένο.. τότε θα σταματήσει σιγά σιγά μόνο του.. και .. γιατί η γη δεν τ'αφήνει να προχωρήσει εύκολα ..
093 **Ερευ** δηλαδή τι εννοείς .. η γη δεν το αφήνει να προχωρήσει εύκολα .. /
094 **Δη** εε.. δηλαδή .. έτσι που τρίβεται το ποδήλατο πάνω στη γη .. εε .. οι ρόδες του ποδηλάτου.. μμ. κάποια στιγμή θα.. μμ. δε θα μπορεί να προχωρήσει άλλο πια .. μπορεί να συνατήσει και καμιά πέτρα και να σταματήσει απότομα .. ή ακόμα και να κινδυνέψει να πέσει...
095 **Ερευ** μάλιστα .. και αυτό νομίζεις ότι έχει να κάνει με κάποια δύναμη.. /
096 **Δη** μμ.. όχι έτσι μου φάινεται εμένα... και άμα ο δρόμος έχει πέτρες ή λακούβες θα σταματήσει πιο γρήγορα ..
097 **Ερευ** μμ χμμ.. καλά .. ας δούμε και την τελευταία κάρτα..
098 **Δη** προχωράει με το σκέϊτμπορντ..
098.5 **Ερευ** >> το ξέρεις το σκέϊτμπορντ.. /



099 **Δη** ναι .. είναι σαν το πατίνι..
100 **Ερευ** ναι .. συνεχίζεις.. /
101 **Δη** εε.. προχωράει με το σκέϊτμπορντ.. δε σπρώχνει με το πόδι... πηγαίνει ολοένα και πιο αργά ... νομίζεις ότι υπάρχουν δυνάμεις εδώ.. / .. ναι υάρχουν .. εε.. οι ρόδες που ακουμάνε πάνω στη γη με το βάρος του σκέϊτμπορντ ... και το παιδί που ακουμπάει πάνω στο σκέϊτμπορντ ... και αυτό με το βάρος που έχει..
102 **Ερευ** μμ χμμ .. γιατί νομίζεις ότι το σκέϊτμπορντ πηγαίνει ολοένα και πιο αργά και κάποια στιγμή θα σταματήσει.. /
103 **Δη** εε... γιατί όταν δεν έχει δύναμη το πατίνι.. δεν μπορεί να συνεχίσει να πηγαίνει .. και αφού το παιδί δεν το σπρώχνει πια με το πόδι του.. εε.. θα σταματήσει σε λίγο.. μμ.. και γιατί το παιδί έχει βάρος που πιέζει το σκέϊτμπορντ.. και αυτό πιέζει το έδαφος..
104 **Ερευ** μάλιστα.. τι εννοείς όταν λες .. πιέζει το έδαφος .. /
105 **Δη** μμ .. το σπρώχνει προς τα κάτω .. άμα το παιδί είναι πολύ βαρύ.. εε.. τότε ίσως να σταματήσει πιο γρήγορα ..
106 **Ερευ** άλλο τίποτε έχεις να προσθέσεις εδώ.. /
107 **Δη** ναι.. για να προχωρήσει το σκέϊτμπορντ πρέπει το παιδί να κάνει .. να βάζει συνέχεια δύναμη με το πόδι του.. αλλιώς η γη δεν το αφήνει να προχωρήσει..
108 **Ερευ** τι εννοείς.. η γη δεν το αφήνει να προχωρήσει .. /
109 **Δη** εε.. με το βάρος του παιδιού.. πιέζει τις ρόδες .. εε.. και έτσι θα σταματήσει.. δε γίνεται αλλιώς ..
110 **Ερευ** μάλιστα... ευχαριστώ πολύ (Δη) .. νομίζω ότι τελειώσαμε τώρα ..
110 **Δη** παρακαλώ .. τίποτα..

Post-Intervention Interview (Δη) or (Di)

001	**Ερευ**	γειά σου (Δη) .. τι κάνεις ..	
002	**Δη**	καλά .. εσείς .. /	
003	**Ερευ**	καλά κι εγώ .. λοιπόν (Δη).. έχω πάλι εδώ μερικές κάρτες που περιέχουν κάποιες εικόνες .. μπορείς να κοιτάζεις τις εικόνες ... να διαβάζεις τις προτάσεις που τις περιγράφουν .. και μετά θα συζητάμε πάνω σε κάθε μια από αυτές τις κάρτες .. εντάξει .. /	
004	**Δη**	ναι .. εντάξει ..	
005	**Ερευ**	ας δούμε λοιπόν την πρώτη κάρτα ..	
006	**Δη**	σηκώνουμε λίγο το τραπέζι από τη μια μεριά .. το βιβλίο δεν τσουλάει προς τα κάτω .. νομίζεις ότι η τριβή το κρατάει εκεί .. / .. ναι .. γιατί:: .. εξαρτάται και από τι είναι φτιαγμένο το βιβλίο ..	
006.5	**Ερευ**	>> μμ χμμ ..	
007	**Δη**	.. αν είναι το βιβλίο λείο ή:: .. είναι τραχύ .. και αυτό ισχύει και για το ξύλο .. του τραπεζιού .. έχει να κανει και με τις επιφάνειες ..	
008	**Ερευ**	και τι ακριβώς συμβαίνει εδώ .. μπορείς να το περιγράψεις .. /	
009	**Δη**	εε.. γιατί το τραπέζι .. αν είναι ξύλινο.. και εδώ θα πρεπεί να είναι ξύλινο .. αφού το βιβλίο δε μετακινείται .. μμ .. το βιβλίο δεν μπορεί εύκολα να κουνηθεί .. και θέλει μεγαλύτερο σήκωμα ..	
010	**Ερευ**	δηλαδή τι συμβαίνει ανάμεσα στις τραχιές επιφάνειες του ξύλου και του βιβλίου .. /	
011	**Δη**	εε .. το βιβλίο ακουμπάει πάνω στο τραπέζι .. αλλά το βάρος του το τραβάει προς τα κάτω .. και κάπως έτσι .. αλλά το ξύλο του τραπεζιού το εμποδίζει να κινηθεί .. γιατί δεν είναι λείο για να γλιστράει εύκολα .. και:: .. έχει δηλαδή κατι σα λακκουβίτσες και υψωματάκια .. που ενώνονται .. ακι έτσι σα να μπλέκονται μεταξύ τους .. κι έστι δημιουργείται η τριβή ..	[δείχνει με το δάχτυλό του κατά μήκος του τραπεζιού]
012	**Ερευ**	και αν το τραπέζι δεν ήταν ξύλινο .. ήταν ας πούμε από φορμάϊκα όπως αυτό εδώ.. τι θα συνέβαινε τότε .. /	[δειχνει το τραπέζι που κάθονται]
013	**Δη**	εε.. τότε θα υπήρχε μεγαλύτερη πιθανότητα να γλιστρήσει το βιβλίο .. γιατί η φορμάϊκα είναι πιο λεία από το ξύλο .. αλλά εξαρτάται και από το πόσο το σηκώνουμε.. γιατί ακόμα και το τρσπέζι αν το σηκώσουμε ψηλά .. τότε το βιβλίο θα αρχίσει να μετακινείται ..	
014	**Ερευ**	αν σου ζητούσα να συμβολίσεις με ενα βελάκι την τριβή .. πώς θα την συμβόλιζες εδώ .. /	
015	**Δη**	εε.. με ένα βέλος έτσι .. προς το τραπέζι .. γιατί το βιβλιο σα να κολλάει στο τραπέζι .. και η τριβή σα να βοηθάει το βάρος του .. και το σπρώχνει πάνω στο τραπέζι ..	[σχηματίζει με το δάχτυλό του ένα βέλος απτο το βιβλίο και με φορά προς το έδαφος]
016	**Ερευ**	μάλιστα .. άλλο τίποτε έχεις να προσθέσεις εδώ .. /	
017	**Δη**	μμ .. ναι υπάρχει κάποια τριβή και στα δύο πόδια του τραπεζιού .. που ακουμπάνε στο έδαφος .. γιατί και αυτά κρατιούνται σε ένα σημείο .. και δε γλιστράνε .. αλλιώς θα γλιστρούσαν και δεν θα μπορούσε το τραπέζι να κρατηθεί πάνω στο κουτί.. μμ .. τίποτε άλλο ..	
018	**Ερευ**	ας δούμε τότε την επόμενη κάρτα ..	
019	**Δη**	περπατάει στο δρόμο .. νομίζεις ότι υπάρχει τριβή εδώ .. / .. ναι υπάρχει τριβή .. στα πόδια του .. δηλαδή στα παπούτσια του ..	
020	**Ερευ**	μμ .. τι εννοείς δηλαδή .. /	
021	**Δη**	εε.. έτσι που περπατάει με τη δύναμη που δίνει .. και:: .. έτσι που φοράει τα παπούτσια του σπρώχνει τη γη και έτσι μπορεί να μετακινηθεί ..	
022	**Ερευ**	σπρώχνει τη γη .. / .. μπορείς να το εξηγήσεις αυτό λίγο .. /	
023	**Δη**	μμ.. έτσι που σηκώνει τα πόδια του και μετά τα ξαναακουμπά στο έδαφος .. σπρώχνει τη γή .. και αυτό γιατί όταν ακουμάνε τα παπούτσια του στο έδαφος .. που είναι τραχύ .. και καθόλου λείο .. εε... το ίδιο είναι και τα παπούτσια ..	
023.5	**Ερευ**	>> μμ χμμ ..	
024	**Δη**	.. εε.. και τότε σα να πιάνονται .. σα να γαντζώνονται αυτές οι τραχύτητες .. γιατί μπαίνουν οι εξοχές της μιας μέσα στις εσοχές της άλλης .. και το αντίθετο .. σα το πάζλ .. που είδαμε όταν κάναμε τα πειράματα για την τριβή .. κι έτσι δημιουργείται μια τριβή .. και μπορούμε και περπατάμε .. αλλιώς δεν θα μορούσαμε .. θα γλιστρούσαμε και θα πέφταμε .. όπως όταν έχει λάδια ο δρόμος ..	
025	**Ερευ**	τι συμβαίνει όταν έχει λάδια ο δρόμος .. /	
026	**Δη**	μμ .. τότε είναι σα να γίνεται πιο λείος .. και έτσι η τριβή γίνεται λιγότερη κι έτσι γλιστράμε ..	
027	**Ερευ**	μάλιστα αν σου ζητούσα να συμβολίσεις με βελάκι την τριβή πώς θα την συμβόλιζες εδώ .. /	
028	**Δη**	εε.. έτσι και έτσι .. με δύο βελάκια .. εδώ στα παπούτσια του .. γιατί:: η τριβή .. σα να βοηθάει το παιδί να ακουμπάει στο έδαφος και να	[σχηματίζει με το δάχτυλό του δύο βέλη, από τα παπούτσια του παιδιού προς το έδαφος]

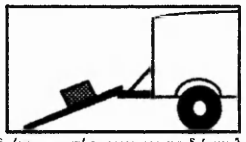
028 **Δη** περπατάει .. όπως και το βάρος του παιδιού το βοηθάει να είναι πάνω στο έδαφος .. επειδή το τραβάει η βαρύτητα ..

029 **Ερευ** μάλιστα.. άλλο τίποτε έχεις να προσθέσεις εδώ ..

030 **Δη** όχι ..

031 **Ερευ** ας δούμε την επόμενη κάρτα ..

032 **Δη** υπάρχει ένα κουτί πάνω σε μια σανίδα στο πίσω μέρος ενός φορτηγού .. το κουτί πατραμένει στη θέση του .. δεν τσουλά .. νομίζεις ότι υπάρχει τριβή εδώ .. / .. ναι ..



[δείχνει αντίστοιχα με το δάχτυλό του σε όλα αυτά τα σημεία]

033 **Ερευ** πού νομίζεις ότι υπάρχει τριβή .. /

034 **Δη** εδώ πέρα στη ρόδα του αυτοκινήτου .. εδώ που η σανίδα ακουμπάει πάνω στην πίσω πόρτα του φορτηγού .. εδώ που ακουμπάει το κιβώτιο πάνω στη σανίδα .. και εδώ που ακουμπάει η σανίδα πάνω στο έδαφος .. άρα έχουμε μία δύο τρεις τέσσερεις τριβές εδώ ..

035 **Ερευ** μάλιστα .. πώς νομίζεις ότι ασκείται η τριβή στο κουτί που είναι πάνω στη σανίδα .. για να αρχίσουμε από εκεί ..

036 **Δη** εε.. εδώ είναι πάλι τραχιές οι επιφάνειες .. και του κουτιού .. άμα είναι από χαρτί ή από ξύλο .. αλλά και της σανίδας που είναι από ξύλο

036.5 **Ερευ** >> μμ χμμ ..

037 **Δη** .. και έτσι τα εξογκώματα και τα βαθουλώματα της μιάς μπαίνουν μέσα στα εξογκώματα και τα βαθουλώματα της άλλης .. όπως και στο βιβλίο πάνω στο τραπέζι .. κι έτσι σα να γαντζώνονται οι επιφάνειές τους .. και ασκείται η τριβή .. που κρατάει το κουτί σταθερό στη θέση του ..

038 **Ερευ** μάλιστα .. και εκεί που ακουμπάει η σανίδα στην πίσω πόρτα του φορτηγού και στο έδαφος .. τι νομίζεις ότι συμβαίνει .. /

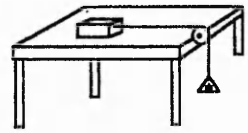
039 **Δη** εε.. υπάρχει πάλι τριβή .. που πάλι σα να γαντζώνει τη σανίδα στην πόρτα .. και με το βάρος της και το βάρος του κουτιού .. κατορθώνει να κρατηθεί εκεί στην άκρια της πόρτας .. και να μην γλιστήσει προς τα κάτω .. εε .. και το φορτηγό όταν θα ξεκινήσει .. θα έχει και αυτό μια τριβή στις ρόδες του .. γιατί θα γαντζώνονται στο έδαφος .. για να μπορέσει να προχωρήσει ..

040 **Ερευ** μάλιστα ... άλλο τίποτε έχεις να συμπληρώσεις εδώ .. /

041 **Δη** μμ .. όχι ..

042 **Ερευ** ας δούμε τότε την επόμενη κάρτα ..

043 **Δη** υπάρχει ένα κομμάτι ξύλου πάνω στο τραπέζι .. στο ξύλο αυτό ασκείται μια δύναμη από το βαράκι που κρέμεται στη άκρη του σπάγγου .. το ξύλο όμως δεν μετακινείται .. μήπως νομίζεις ότι η τριβή το κρατάει εκεί .. /.. μμ.. αυτό είναι σαν τα πειράματα που κάναμε στην τάξη ..



044 **Ερευ** ναι .. είναι κάτι από αυτά που κάναμε .. τι νομίζεις λοιπόν ότι συμβαίνει εδώ .. /

045 **Δη** το αν θα μετακινηθεί το ξύλο εδώ .. εξαρτάται από τι βαράκι θα του βάλουμε .. δηλαδή .. όπως κάναμε και στην τάξη .. ζυγίσαμε το ξύλο και μετά κρεμάσαμε διάφορα βαράκια .. και βρήκαμε ότι χρειάζεται ένα βάρος .. περίπου ένα τέταρτο του βάρους του ξύλου για να αρχίσει το ξύλο να κινείται ..

045.5 **Ερευ** >> μμ χμμ ..

046 **Δη** .. εε.. και εξαρτάται και από το αν είναι λείο η τραχύ το τραπέζι .. δηλαδή από το αν είναι ξύλινο .. ή και αν έχουμε βάλει γυαλόχαρτο .. και τότε θα έχει μεγαλύτερη τριβή .. και θα χρειαστεί να κρεμάσουμε περισσότερο βάρος .. πάνω από το μισό του βάρους του ξύλου για να αρχίσει να κινείται ..

047 **Ερευ** στην πρίπτωση που έχουμε κρεμάσει κάποιο βάρος αλλά το κομμάτι το ξύλο δεν μετακινείται .. νομίζεις ότι υπάρχει τριβή .. /

048 **Δη** μμ.. ναι υπάρχει τριβή .. γιατί γαντζώνονται οι τραχιές επιφάνειες .. του τραπεζιού και του ξύλου .. και έτσι δυσκολεύεται να μετακινηθεί το ξύλο .. γιατί σα να το συγκρατεί .. έτσι προς τα πίσω η τριβή ..

049 **Ερευ** μάλιστα .. αν σου ζητούσα να συμβολίσεις τη δύναμη της τριβής πώς θα την συμβόλιζες .. /

[σχηματίζει ένα βέλος από το ξύλο και με φορά προς το έδαφος]

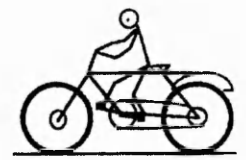
050 **Δη** μμ.. έτσι .. προς τα κάτω .. γιατί σα να σπρώχνει το ξύλο προς το τραπέζι .. σα να το πιέζει μαζί με το βάρος του προς τα κάτω .. και γι αυτό αντιστέκεται στην άλλη δύναμη από το βαράκι ..

051 **Ερευ** άλλο τίποτε έχεις να προσθέσεις εδώ.. /

052 **Δη** μμ .. μπα μάλλον όχι ..

053 **Ερευ** ας δούμε τότε την επόμενη κάρτα ..

054 **Δη** έχει σταματήσει να κάνει πετάλι .. δε χρησημοποιεί τα φρένα .. πηγαίνει ολοένα και πιο αργά .. νομίζεις ότι η τριβή μειώνει την ταχύτητα του ποδηλάτου .. / .. εε..4 .. ναι τη μειώνει .. γιατί αφού το παιδί δε βάζει άλλο δύναμη στο ποδήλατο .. γιατί έχει σταματήσει να κάνει πετάλι .. τότε το ποδήλατο απλά συνεχίζει να πηγαίνει .. για λίγο ..



054.5 **Ερευ** >> μμ χμμ ..

055 **Δη** .. αλλά επειδή οι ρόδες όπως γυρίζοιν τρίβονται στο έδαφος .. δηλαδή οι ρόδες σα να δυσκολεύονται λίγο όταν γυρνάνε πάνω στη γη .. και γι αυτό το ποδήλατο χάνει σιγά σιγά την ταχύτητά του .. και κάποτε θα σταματήσει ..

056 **Ερευ** πώς νομίζεις ότι υπάρχει τριβή στις ρόδες .. /

057 **Δη** εε.. οι ρόδες έχουν μια τραχιά επιφάνεια .. έχουν κάτι σαν αυλάκια και σχισμές .. και καθώς γυρνάνε .. είναι σα να κουτουλάνε πάνω στα εξογκώματα του δρόμου .. ή και σα να πέφτουν στις λακκούβες .. και άμα έχει και πολλές μεγάλες λακκούβες ο δρόμος θα σταματήσει και πιο εύκολα ..

058 **Ερευ** αν σου ζητούασα να συβολίσεις την τριβή με ένα βελάκι .. πώς θα την συμβόλιζες εδώ .. /

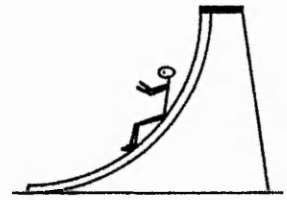
[σχηματίζει δύο βέλη από τις ρόδες και με φορά προς τη γη]

059 **Δη** εε.. θα τη συμβόλιζα με δύο βελάκια .. ενα έτσι κι ένα έτσι .. απο τις δύο ρόδες του .. γιατί πάλι σπρώχνει το ποδήλατο στο έδαφος μαζί με το βάρος του ..

060 **Ερευ** άλλο τίποτε έχεις να προσθέσεις εδώ .. /

061 **Δη** εε.. ναι .. υπάρχει επίσης τριβή και εκεί που τα πόδια του παιδιού ακουμπούν στα πετάλια του ποδηλάτου .. και έπισης και εκεί που το παιδί κάθεται πάνω στη σέλλα ..

062 **Ερευ** μάλιστα άς δούμε και την τελευταία κάρτα .. κοίταξε πρώτα την Α περίπτωση και έπειτα τη Β .. /



063 **Δη** γλιστράει πάνω στην τσουλήθρα .. νομίζεις ότι υπάρχει τριβή εδώ .. / .. εε.. υπάρχει τριβή σ' αυτή την περίπτωση .. εκεί που ακουμπάει το παιδί απάνω στην τσουλήθρα .. δηλαδή στα:: .. παπούτσια του και .. στο παντελόνι του ..

064 **Ερευ** μάλιστα .. και ..

064.5 **Δη** >> **α**.. και όσο λείες και να φτιάχνονται οι τσουλήθρες για να γλιστράνε εύκολα τα παιδιά .. πάντα έχουν .. πάντα είναι λίγο τραχιές .. κι έτσι .. όπως γλιστάνε τρίβονται πάντα .. και γι αυτό δεν πηγαίνουν και με πάρα πολλή μεγάλη ταχύτητα ..

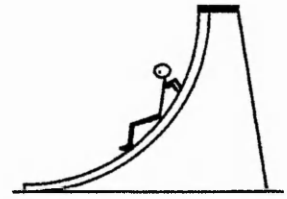
[σχηματίζει ένα βέλος από το παιδί και με φορά προς τα κάτω]

065 **Ερευ** ναι .. και πώς θα συμβόλιζες την τριβή εδώ με ένα βέλος ..

066 **Δη** έτσι προς τα κάτω .. γιατί σπρώχνει το παιδί και σα να το κολλάει λίγο στην τσουλήθρα ..

067 **Ερευ** διαφέρει καθόλου η τριβή .. από το βάρος του παιδιού .. /

068 **Δη** ναι .. γιατί σα να το σπρώχνει και να το συγκρατεί προς τα πίσω .. η τριβή .. ενώ το βάρος του παιδιού το τραβάει μόνο προς τα κάτω ..



069 **Ερευ** μάλιστα και τι συμβαίνει στη Β περίπτωση .. μπορείς να διαβάσεις .. /

070 **Δη** κρατάει σταθερά με τα χέρια του πάνω στην τσουλήθρα .. δε γλιστράει .. νομίζεις ότι υπάρχει τριβή εδώ .. / .. εε..4.. ναι υπάρχει κι εδώ τριβή .. γιατί εκτός από τα πόδια του και το παντελόνι του .. το παιδί σα να κολλάει με τα χέρια του πάνω στην τσουλήθρα .. και εκεί ασκεί μεγάλη τριβή ..

071 **Ερευ** δηλαδή τι νομίζεις ότι συμβαίνει με τα χέρια του .. /

072 **Δη** εε.. πιάνει δυνατά .. και έτσι όπως πιέζει με τα χέρια του .. εε.. με τις παλάμες του πάνω στην τσουλήθρα .. σα να κολλάει .. σα βεντούζα .. πάνω στην τσουλήθρα .. κι αυτό τον βοηθάει να μείνει εκεί πάνω .. δηλαδή η τριβή που γίνεται στις παλάμες του .. κάπως έτσι .. δεν μπορώ να το πω καλύτερα..

073 **Ερευ** μάλιστα .. που νομίζεις ότι υπάρχει περισσότερη τριβή εδώ .. στην Α περίπτωση ή στη Β .. /

[δείχνει στη Β περίπτωση στην εικόνα]

074 **Δη** εε .. στη δεύτερη περίπτωση .. γιατί .. το παιδί .. εε.. στο παιδί πρέπει να ασκηθεί πολλή τριβή γαι να κρατηθεί ακίνητο πάνω στην τσουλήθρα .. α .. και γιατί έχουμε περισσότερα σημεία επαφής .. και έτσι το παιδί σα να τρίβεται πιο πολύ πάνω στη τσουλήθρα..

075 **Ερευ** μάλιστα άλλο τίποτε έχεις να προσθέσεις εδώ .. /

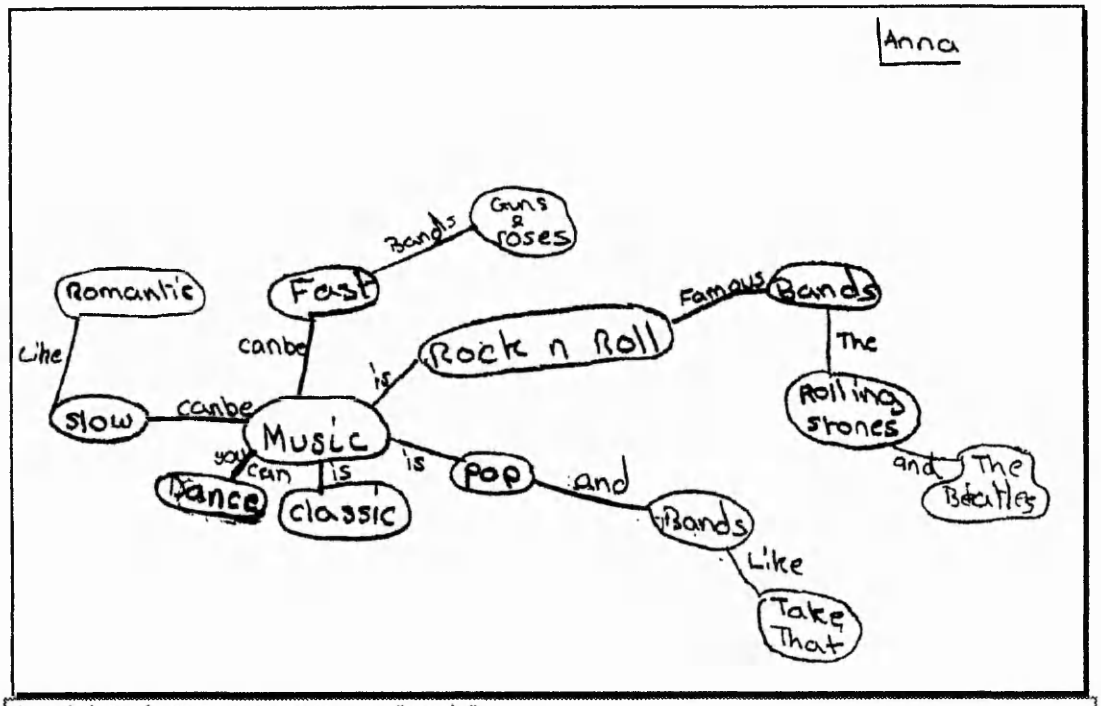
076 **Δη** μμ.. όχι .. αυτά ..

077 **Ερευ** εντάξει (Δη) .. νομίζω ότι τελειώσαμε τώρα .. σ' ευχαριστώ πολύ ..

078 **Δη** κι εγώ ευχαριστώ .. γειά σας ..

APPENDIX VI

Some of the children's introductory concept maps and respective commentaries from one of their classmates.

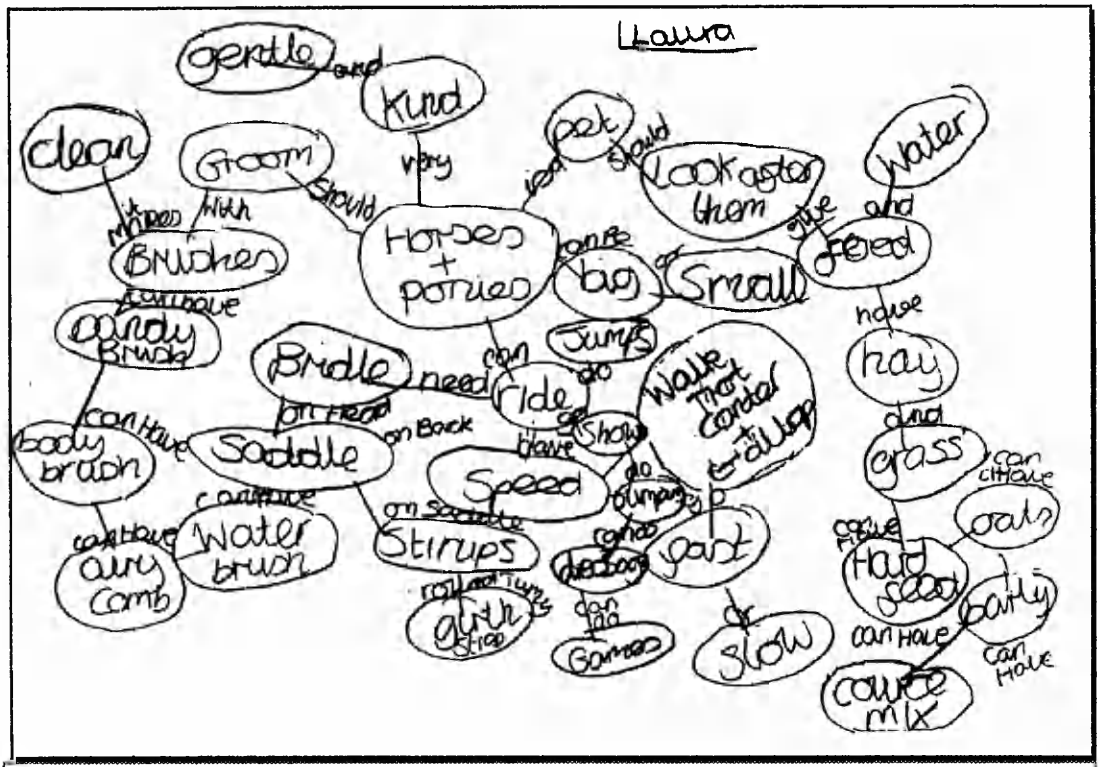


Anna's introductory concept map on "music".

This is all about music.
It shows that the music can be fast or slow.
and all the different sorts of music that there is.
Like romantic, rock and roll, pop, classical and Dancing music.
It shows that SLOW music can be romantic and fast music represents Guns and roses

(This is Anna's)
as understood by Laura

Laura's commentary on Anna's concept map.



Laura's introductory concept map on "horses and ponies".

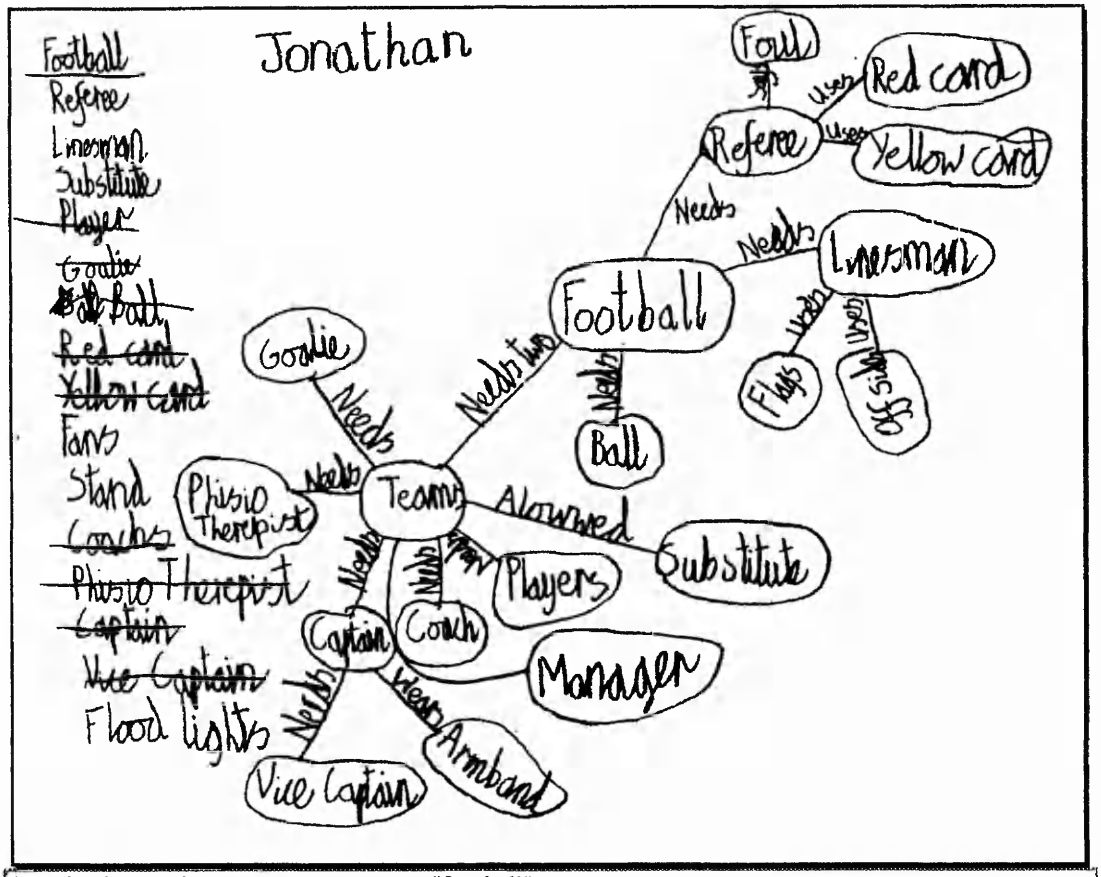
Horses and Ponies are very kind and Gentle. They can be a pet. You should look after them, give them food and water. For their food they can have: hay, grass, hard feed, coarse mix, barley and oats. They can be big or small, do jumps. They can ride slow or fast. They need speed, girthstrap, stirups, saddle, Bridle. They should have a Groom which should clean them and Boursh them. There is a water brush, airy comb, body brush and Dandy brush. They can Walk, Trot canter and gallop.

by Julia

from Laura's

map!

Julia's commentary on Laura's concept map.

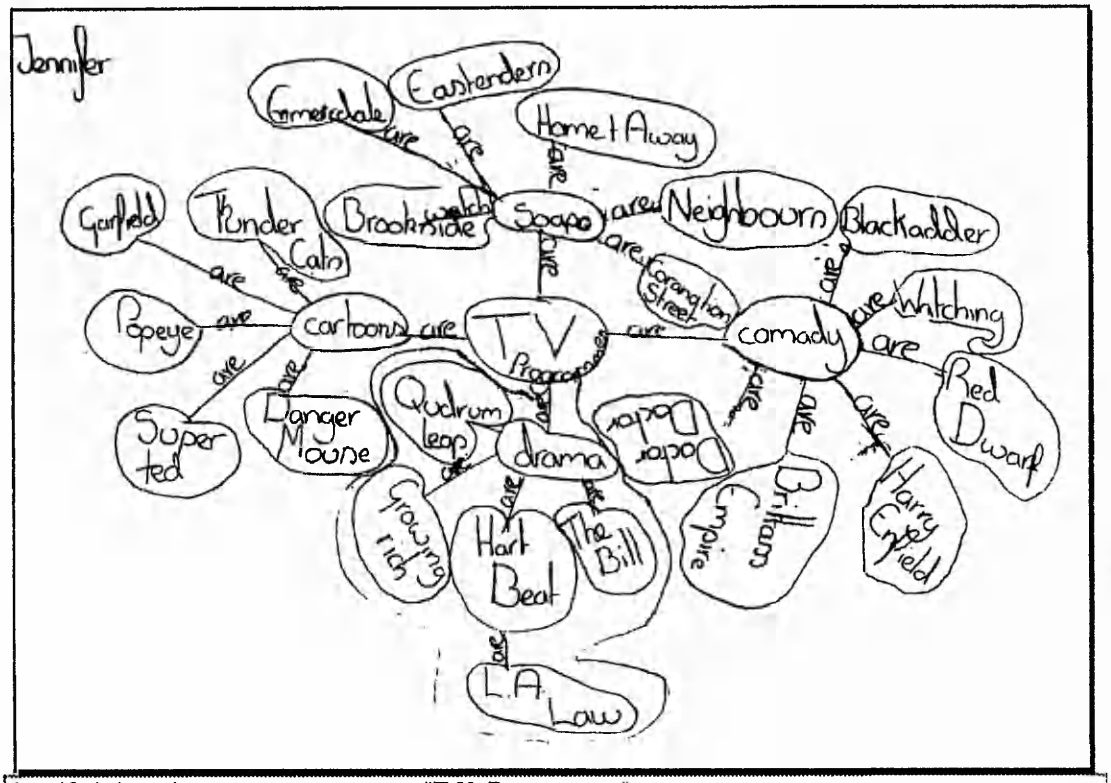


Jonathan's introductory concept map on "football".

this about Football it shows that Football needs two teams to play a game and ~~a~~ alowwed substitute And you also need a ~~a~~ referee who uses the yellow card and red card and that he says Foul. Teams also need players and a goalie. for football you ~~needs~~ need linesman who uses flags. It also shows that teams a coach, a manager, captain and vice captain.

this is Jonathan's map. by Anna

Anna's commentary on Jonathan's concept map.



Jennifer's introductory concept map on "T.V. Programmes".

Isla

TV Programmes are Dramas, comadys, soaps, cartoons.

Dramas are The Bill, Hart Beat, La Law, growing rich, quadrum leap

Comadys are Blackadder; watching, Red Dwarf, Harry Enfield, Brittas Empire, Doctor Doctor,

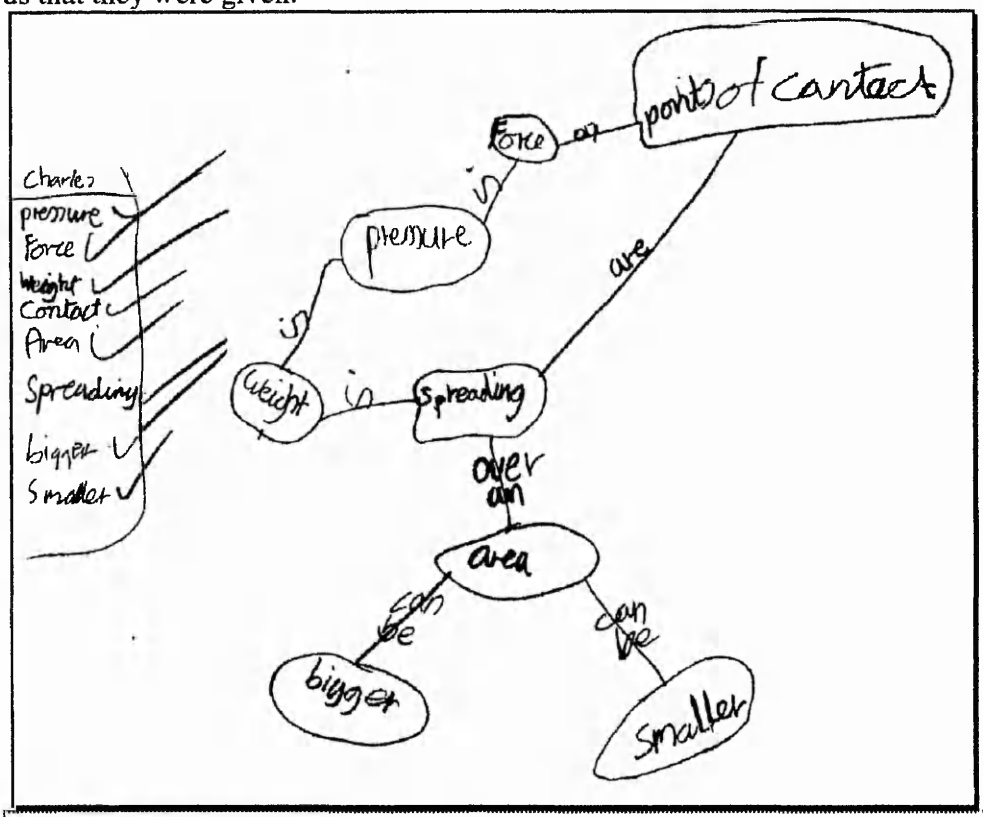
Soaps are coronation Street; Neighbours, Home and Away, Eastenders, Emmerdale, Brookside,

cartoons are Danger mouse, super tea, Popeye, Garfield, Thunder cats,

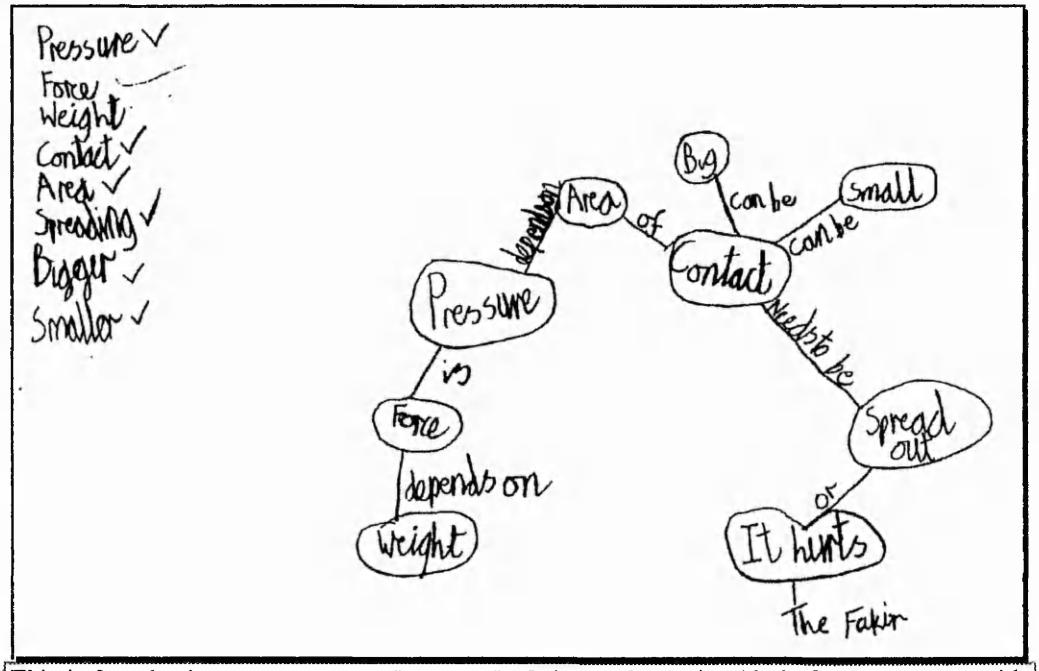
This is Jennifer's Map.

Isla's commentary on Jennifer's concept map.

Two of the children's concept maps on the concept of "pressure". Note the list of words that they were given.



This is Charles' concept map on "pressure". Note the cross link where *pressure is a force on points of contact which are* ***spreading*** *over an area* and *pressure is weight which is* ***spreading*** *over an area.*



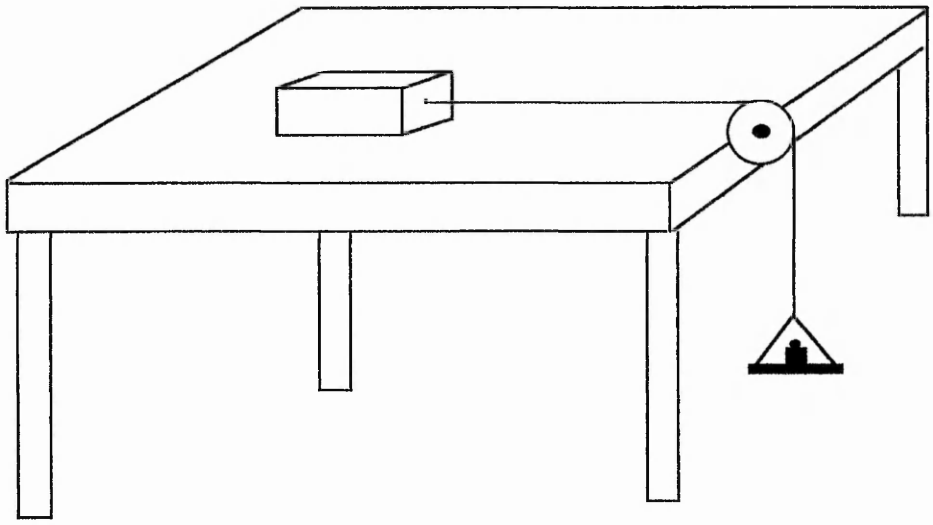
This is Jonathan's concept map on "pressure". It is a rather string kind of concept map, with propositional relations among the listed words. Note the right end of the concept map where an opinion on the "fakir problem" is expressed: *the area of contact needs to be spread out, otherwise it hurts the fakir.*

APPENDIX VII

INVESTIGATION

TABLE 1.

There are some blocks of wood on your table. You may tie a piece of string on one of these blocks and then pass it around a pulley which is fixed at the edge of the table. You may tie a plastic tray at the end of the string. You can put some weights there (see the following drawing).



ACTIVITIES

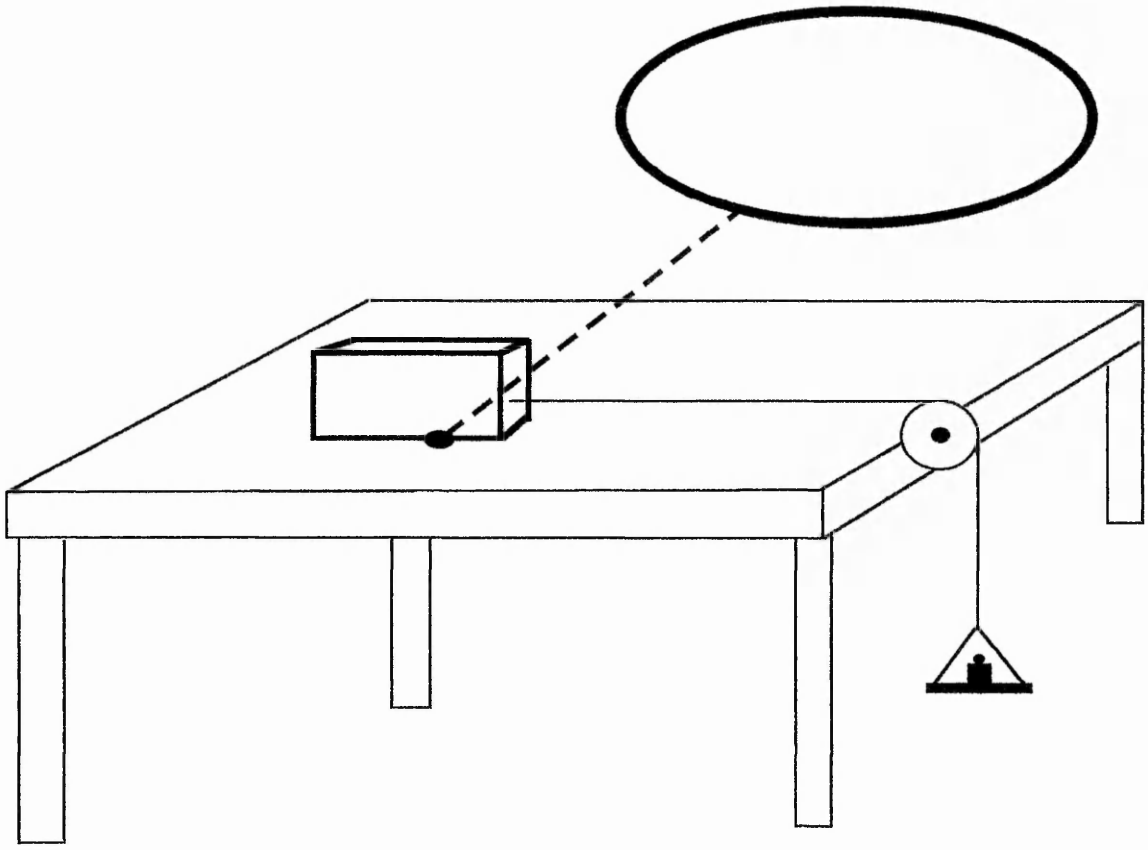
1. **Weigh your block of wood.**
2. **Add carefully weights on the tray until the block starts sliding gently.**
3. **Note how much weight you have to use in order to slide the block of wood on the table.**
4. **Compare this force with the weight of the block. What do you observe?**
5. **Add another block of wood on top of the one you already have on the table. Repeat activities 2 & 3.**
6. **Compare the force you had to use in order to slide the blocks of wood on the table with their weight. What do you observe? Record your observations.**

Group work

Group leader:
Performer:
Observer(s):
Scribe:

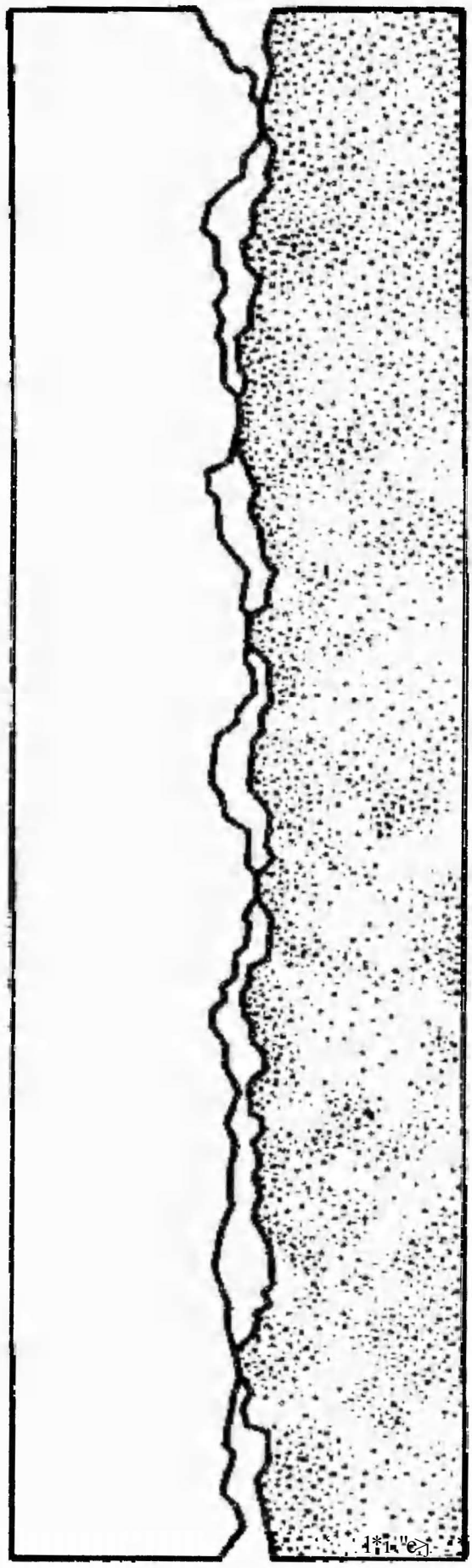
Attention: Add the weights gently on the tray. Try not to move or shake the table while you are doing your investigation.

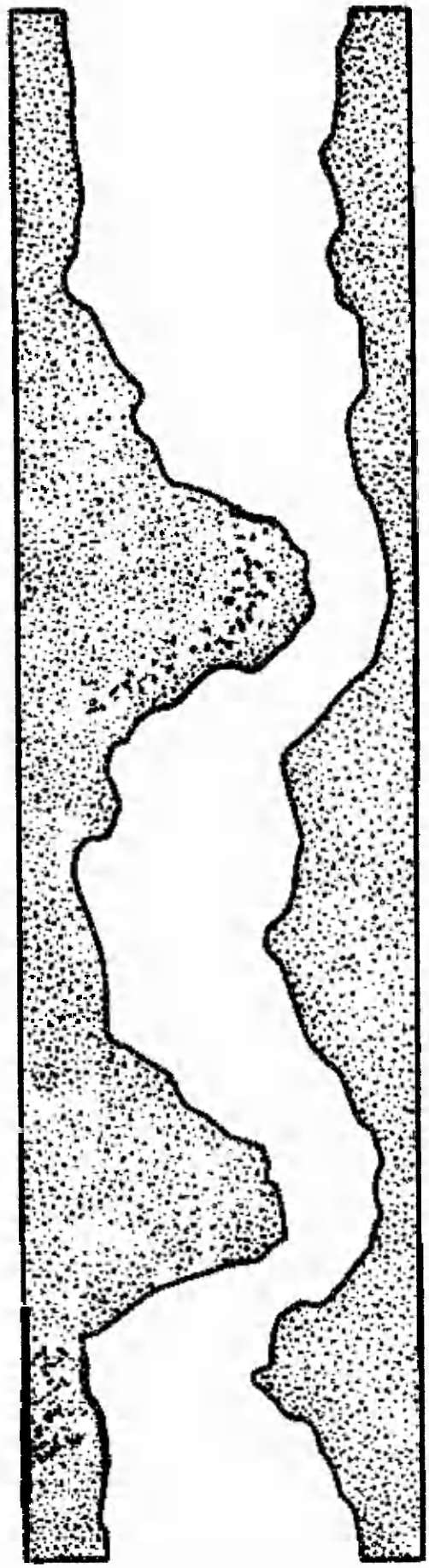
NAME: _____



If we magnify a small part of the area of contact of the block of wood and the table, could you draw how would that look like? Use the space in the circle provided.

Write, in your own words, how do you think, this interlocking of surfaces (when one goes into the other), effects friction when we try to slide an object on a surface.

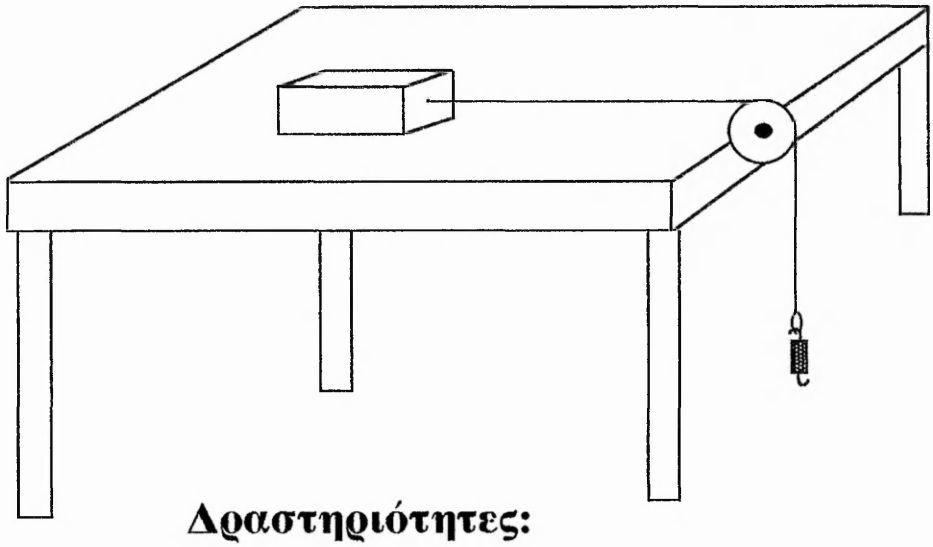




APPENDIX VIII

Φύλλο Εργασίας

Υπάρχει ένα κομμάτι ξύλο πάνω στο τραπέζι. Είναι συνδεμένο με ένα κομμάτι σπάγγο που περνά γύρω από μια τροχαλία και καταλήγει σε μια θηλειά, όπου μπορούμε να κρεμάμε διάφορα βάρη.



Δραστηριότητες:

1. **Ζυγίστε το κομμάτι του ξύλου που βρίσκεται πάνω στο τραπέζι.**
2. **Κρεμάστε προσεχτικά βάρη στη θηλειά μέχρι το ξύλο να αρχίσει να τσουλάει αργά και σταθερά.**
3. **Σημειώστε πόσο βάρος θα έπρεπε να χρησιμοποιήσετε για να αρχίσει το ξύλο να τσουλάει αργά και σταθερά**
4. **Συγκρίνετε το βάρος του ξύλου με το βάρος που χρησιμοποιήσατε για να αρχίσει το ξύλο να τσουλά αργά και σταθερά. Τι παρατηρείτε;**
5. **Προσθέστε άλλο ένα κομμάτι ξύλο πάνω σ' αυτό που έχετε ήδη στο τραπέζι. Επαναλάβετε τις δραστηριότητες 2 & 3.**
6. **Συγκρίνετε το βάρος που έπρεπε να χρησιμοποιείσετε για να τσουλήσουν τα κομμάτια από ξύλο πάνω στο τραπέζι, με το βάρος των ξύλων. Τι παρατηρείτε;**

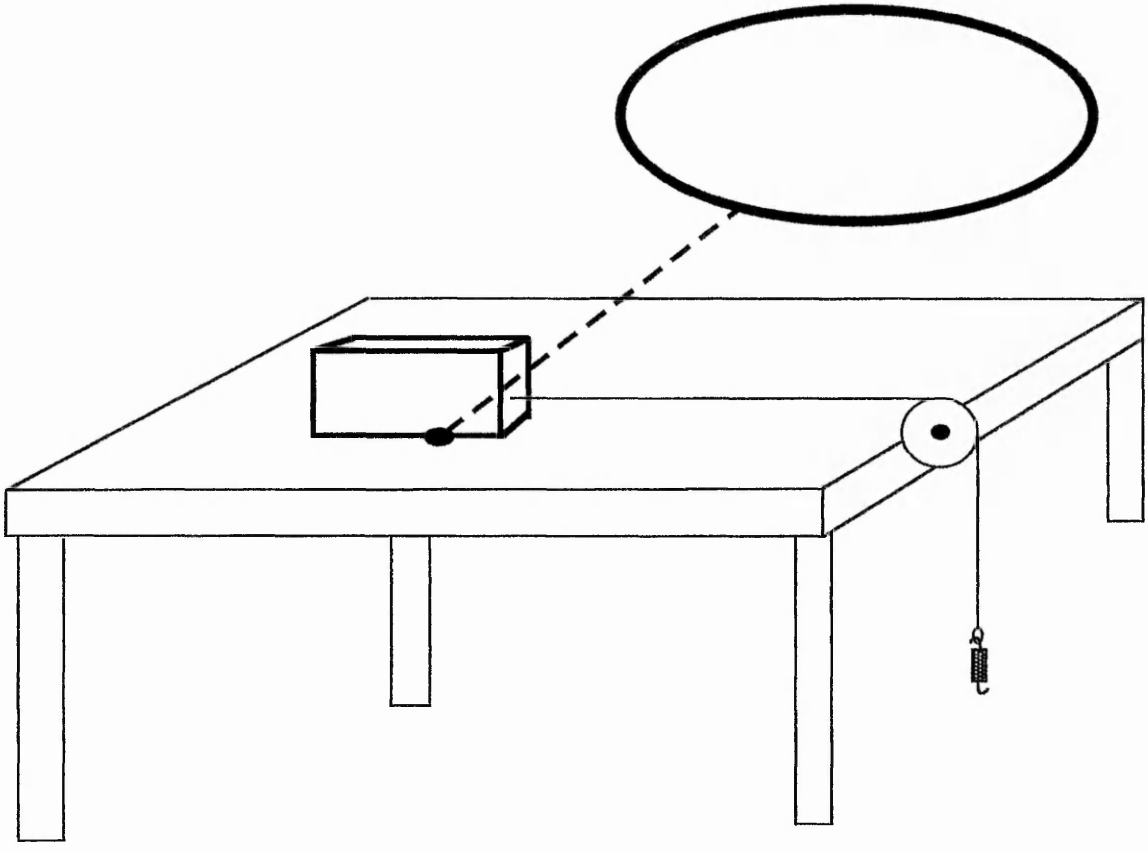
Ομαδική εργασία:

Κάθε ομάδα να εργαστεί συλογικά. Στο τέλος της εργασίας, ένας εκπρόσωπος της ομάδας να ανακοινώσει τα αποτελέσματα από τις δραστηριότητες της ομάδας.

Προσοχή:

Να κρεμάτε τα βάρη προσεχτικά το ένα κάτω από το άλλο. Μην κουνάτε το τραπέζι όταν προσπαθείτε να εκπληρώσετε τις παραπάνω δραστηριότητες.

Όνομα: _____

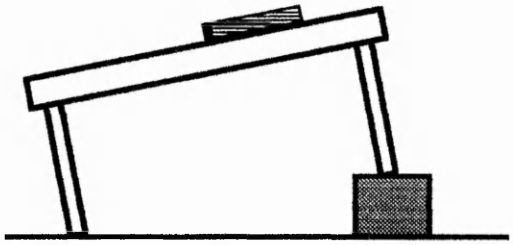


Μεγενθύνουμε ένα μικρό κομμάτι της επιφάνειας επαφής του ξύλου και του τραπεζιού. Μπορείτε να σχεδιάσετε πώς θα φαινόταν αυτή η μεγένθυση; Χρησιμοποιείστε το χώρο που υπάρχει μέσα στο κύκλο.

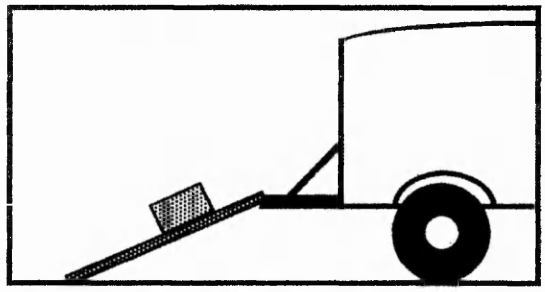
Πώς νομίζεις ότι, οι μικρές εσοχές και εξοχές των δύο επιφανειών, προκαλούν δυνάμεις τριβής, με αποτέλεσμα να δυσκολεύουν ή ακόμα και να κάνουν αδύνατη την κίνηση των σωμάτων;

Όνομα: _____

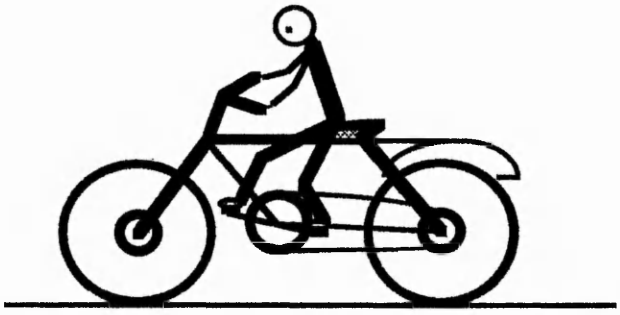
Παρακάτω βλέπεις μερικές εικόνες, οι οποίες περιγράφονται με μία πρόταση. Μπορείς να σχεδιάσεις με ένα βέλος τη δύναμη της τριβής, όπου νομίζεις ότι υπάρχει;



α. Το βιβλίο δεν τσουλάει πάνω στο τραπέζι.



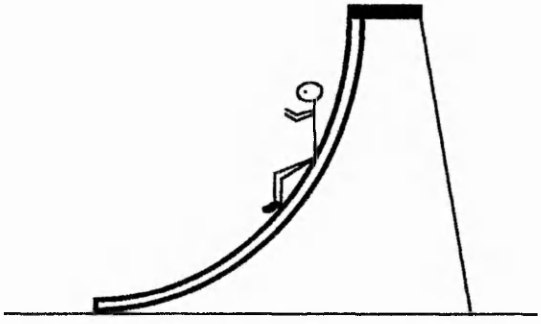
β. Το κουτί που βρίσκεται πάνω στην σανίδα δεν τσουλάει.



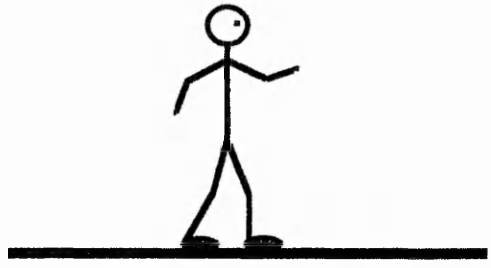
γ. Το ποδήλατο πηγαίνει αργά, χωρίς να χρησιμοποιούνται τα πετάλια και σε λίγο θα σταματήσει.



δ. Τσουλάει με ταχύτητα στην κατηφόρα



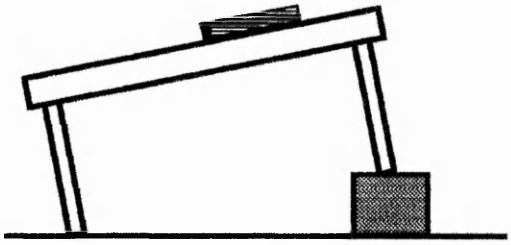
ε. Γλιστράει πάνω στην τσουλήθρα.



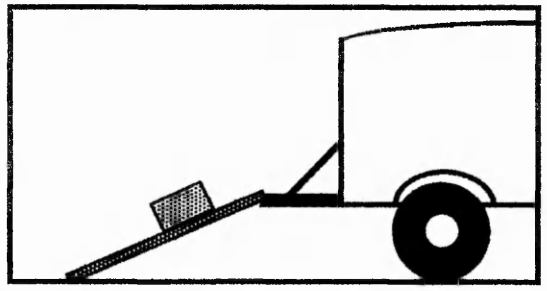
στ. Περπατάει στο δρόμο.

Name: _____

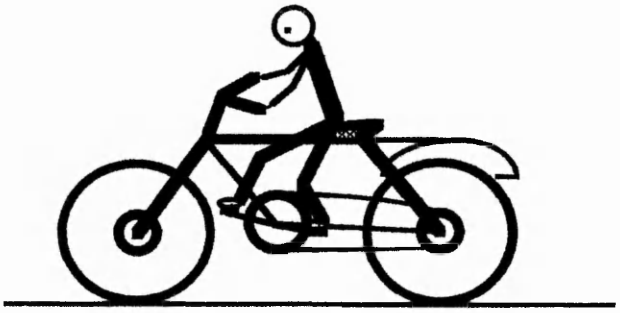
Here are some pictures which are also described with a sentence. Could you draw the arrow of the force of friction, wherever you think it exists?



a. The book does not slide on the table.



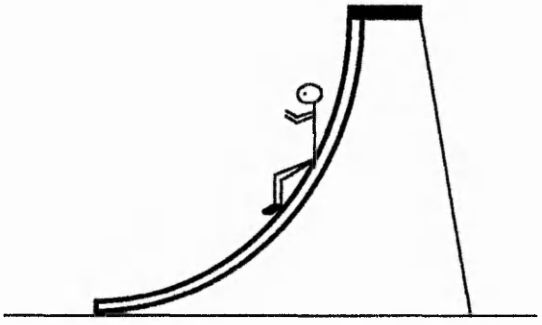
b. There is a box on the slope and it does not slide down.



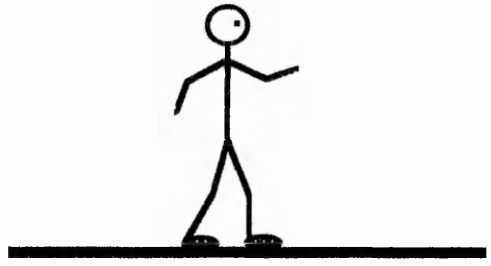
c. The bicycle is going slowly and it will stop soon. The person is not pedalling.



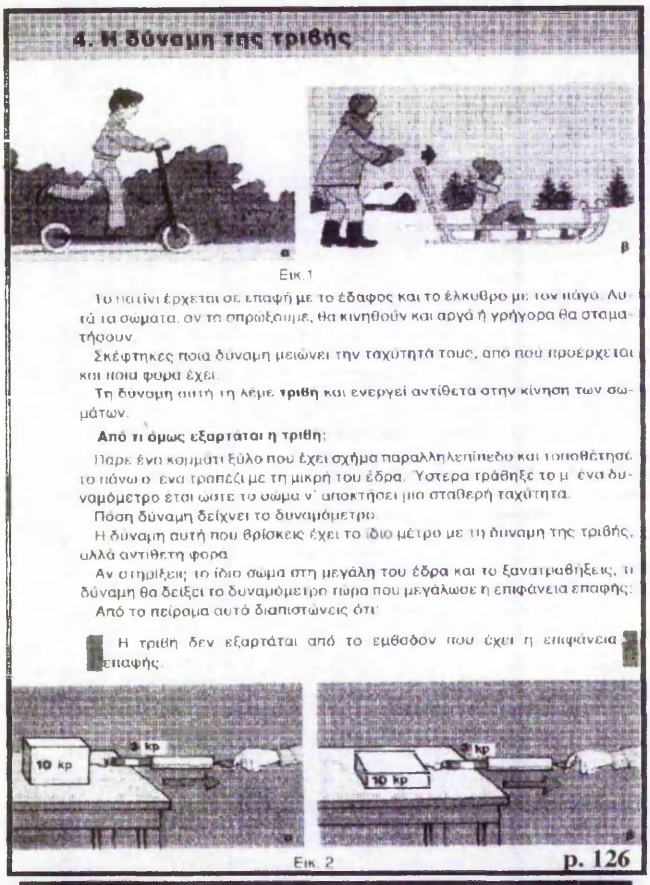
d. Mooving fast down the road .



e. Coming down the slide.



f. Walking along the road.



4. Η δύναμη της τριβής

Εικ. 1

Το ποδήλατο έρχεται σε επαφή με το έδαφος και το έλκυθρο με τον πάγο. Αυτά τα σώματα, αν τα σπρώξουμε, θα κινηθούν και αργά ή γρήγορα θα σταματήσουν.

Σκέφτηκες ποια δύναμη μειώνει την ταχύτητά τους, από που προέρχεται και ποια φορά έχει.

Τη δύναμη αυτή τη λέμε **τριβή** και ενεργεί αντίθετα στην κίνηση των σωμάτων.

Από τι όμως εξαρτάται η τριβή;

Πάρε ένα κομμάτι ξύλο που έχει σχήμα παραλληλεπίπεδο και τοποθέτησέ το πάνω σ' ένα τραπέζι με τη μικρή του έδρα. Ύστερα τράβηξέ το με ένα δυναμόμετρο έτσι ώστε το σώμα ν' αποκτήσει μια σταθερή ταχύτητα.

Πόση δύναμη δείχνει το δυναμόμετρο;

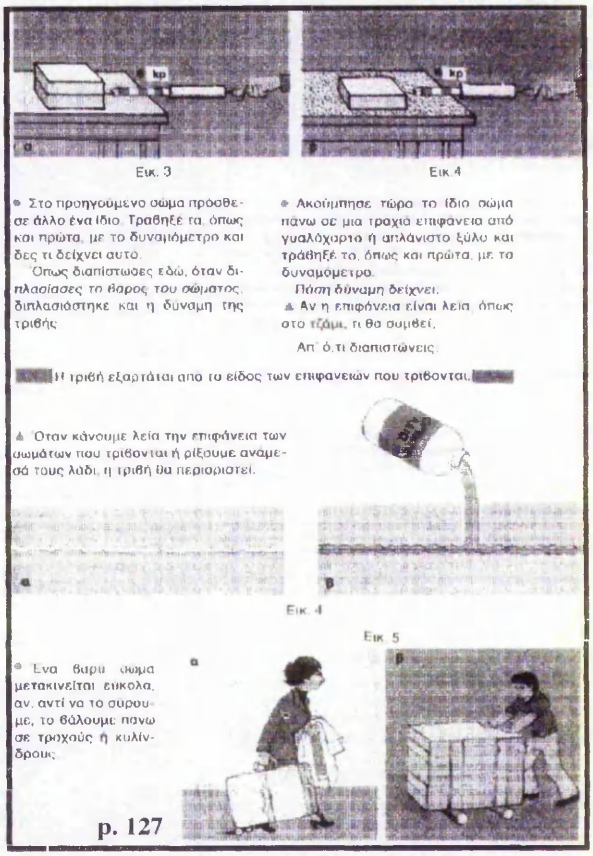
Η δύναμη αυτή που βρίσκεις έχει το ίδιο μέτρο με τη δύναμη της τριβής, αλλά αντίθετη φορά.

Αν σταμπάρεις το ίδιο σώμα στη μεγάλη του έδρα και το ξανατραβήξεις, τι δύναμη θα δείξει το δυναμόμετρο τώρα που μεγάλωσε η επιφάνεια επαφής;

Από το πείραμα αυτό διαπιστώνεις ότι:

Η τριβή δεν εξαρτάται από το εμβαδόν που έχει η επιφάνεια επαφής.

Εικ. 2



Εικ. 3

Εικ. 4

• Στο προηγούμενο σώμα προσθέσε άλλο ένα ίδιο. Τραβήξε τα, όπως και πρώτα, με το δυναμόμετρο και δες τι δείχνει αυτό.

Όπως διαπίστωσες εδώ, όταν διπλασίασες το βάρος του σώματος, διπλασιάστηκε και η δύναμη της τριβής.

• Ακούμπησε τώρα το ίδιο σώμα πάνω σε μια τραχιά επιφάνεια από γυαλόχαρτο ή απλάνιστο ξύλο και τράβηξέ το, όπως και πρώτα, με το δυναμόμετρο.

Πόση δύναμη δείχνει;

▲ Αν η επιφάνεια είναι λεία, όπως στο τζάμι, τι θα συμβεί;

Απ' ό,τι διαπιστώνεις:

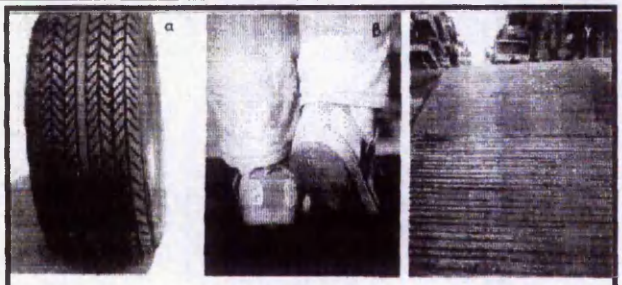
Η τριβή εξαρτάται από το είδος των επιφανειών που τρίβονται.

▲ Όταν κάνουμε λεία την επιφάνεια των σωμάτων που τρίβονται ή ρίξουμε ανάμεσά τους λάδι, η τριβή θα περιοριστεί.

Εικ. 4

Εικ. 5

• Ένα βαρύ σώμα μετακινείται εύκολα, αν, αντί να το σύρουμε, το βάλουμε πάνω σε τροχούς ή κυλίνδρους.



Εικ. 6

• Στις διαφορές δραστηριότητές μας άλλοτε επιδιώκουμε να αυξήσουμε την τριβή και...



...άλλοτε να την ελαττώσουμε.

Εικ. 7

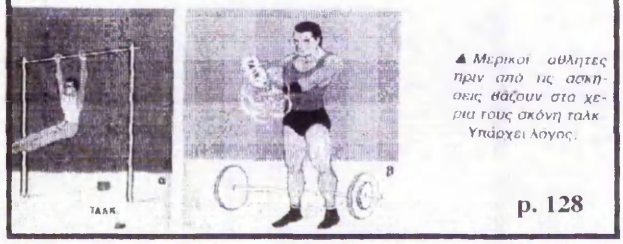
Ελέγχω ό,τι μαθαίνω

▲ *Γιατί τα αυτοκίνητα γλιστρούν εύκολα, όταν οι δρόμοι είναι θρεγμένοι ή χιονισμένοι;*

▲ ***Βρες τη σωστή πρόταση.***

Εύκολα με θρεγμένα χέρια: — *Ανοίγω το θιδωτό μπουκάλι.*
— *Γυρίζω το στρογγυλό πόμολο της πόρτας.*
— *Πλένω τον πηλό.*

Εικ. 8



▲ *Μερικοί αθλητές πριν από τις ασκήσεις βάζουν στα χέρια τους σκόνη ταλκ. Υπάρχει λόγος;*

The Teaching Unit of the Force of Friction

Here are three pages (126-128) from the Greek national text book "**I Investigate the Natural World**", Part A, E' Grade. In the school year 1995-96 the text book reached its 12th reprint and approximately 175000 copies have been destributed. It was originally published in 1984 and since then it is mainly reprinted without any major changes or revisions. In the pages that follow the Greek text from the unit "**The force of friction**" has been translated. Thus, the presentation of the topic can be viewed in greater detail. Respective comments and further information for the teacher, can be found in the teacher's book. A translation of the page that refers to this topic (p. 65, from the teacher's book), follows after the presentation of the teaching unit.

4. The force of Friction



Εικ. 1 (Pict. 1)

The skateboard comes to contact with the ground and the sledge with the ice. If we push these bodies they will move and sooner or later they will stop.

Have you thought which force decreases their speed, where it comes from and which is its direction?

We call this force **friction** and it acts against the movement of bodies.

What does friction depend on, though ?

Take a piece of wood that has the shape of a parallelepipedon and put it on a table on its small side. Then pull it with a dynamometer in a way that the body will obtain a constant velocity.

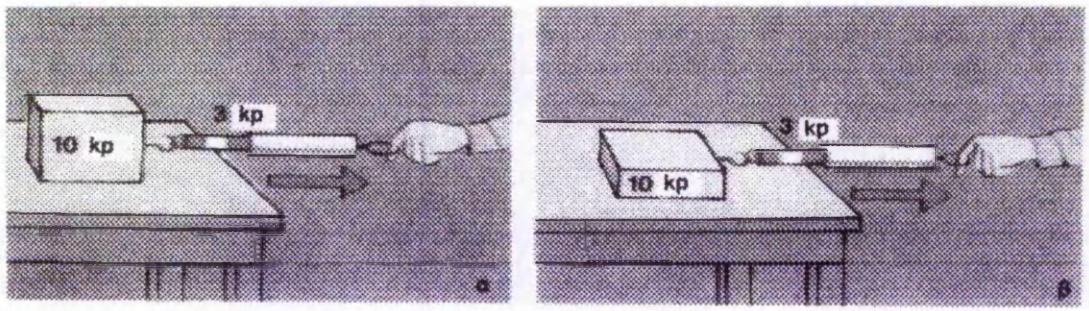
How much force does the dynamometer indicate ?

The force that you found has the same measure with the force of friction but an opposite direction.

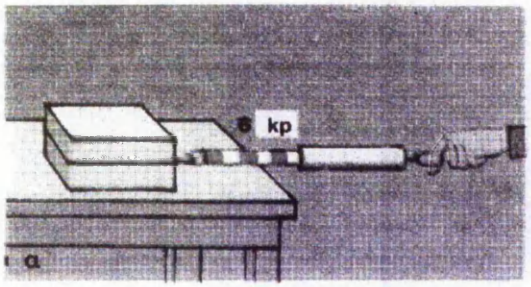
If you put the same body on its large side and you pull it again, what force will the dynamometer indicate, now that the area of contact got larger ?

From this experiment you ascertain that:

Friction does not depend on the area of the surface of contact.



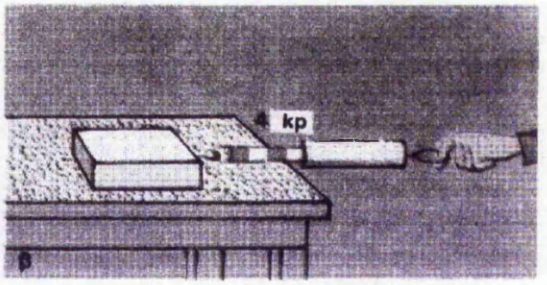
Εικ. 2 (Pict. 2)



Εικ. 3 (Pict. 3)

To the previous body add another one identical. Pull them, like before, with the dynamometer and see what it shows.

As you acertained here, when you doubled the weight of the body, the force of friction was also doubled.



Εικ.4 (Pict. 4)

Now lay the same body on a rough surface of sandpaper or unplaned wood and pull it, as before, with the dynamometer.

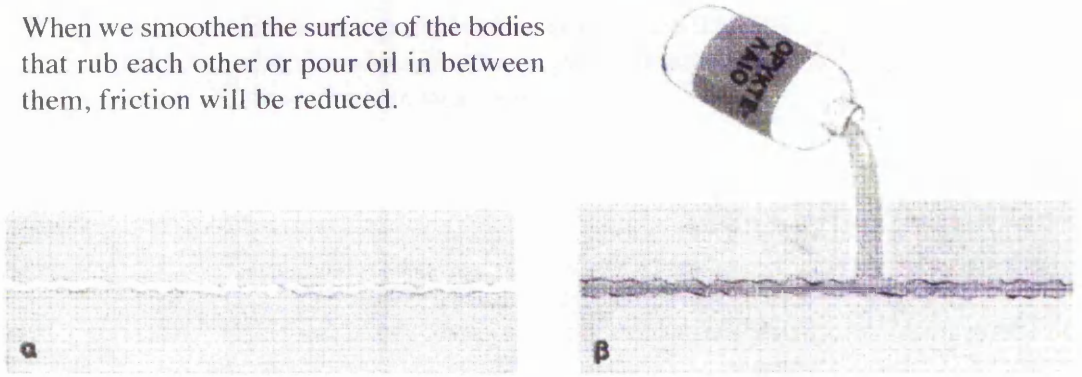
How much force does it indicate?

● If the surface is smooth, just like glass, what will happen?

From what you ascertain:

Friction depends on the sort of surfaces that rub each other

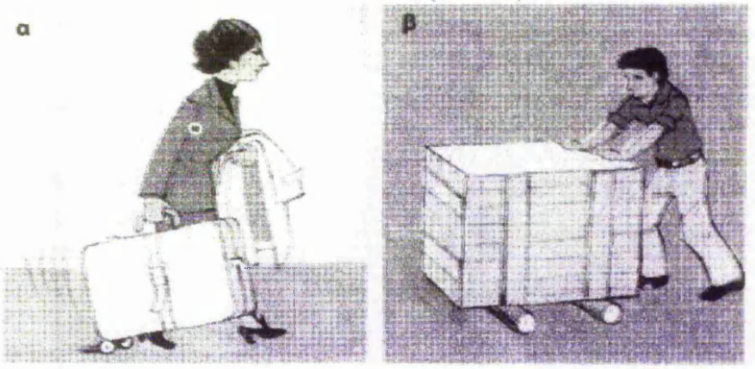
When we smoothen the surface of the bodies that rub each other or pour oil in between them, friction will be reduced.

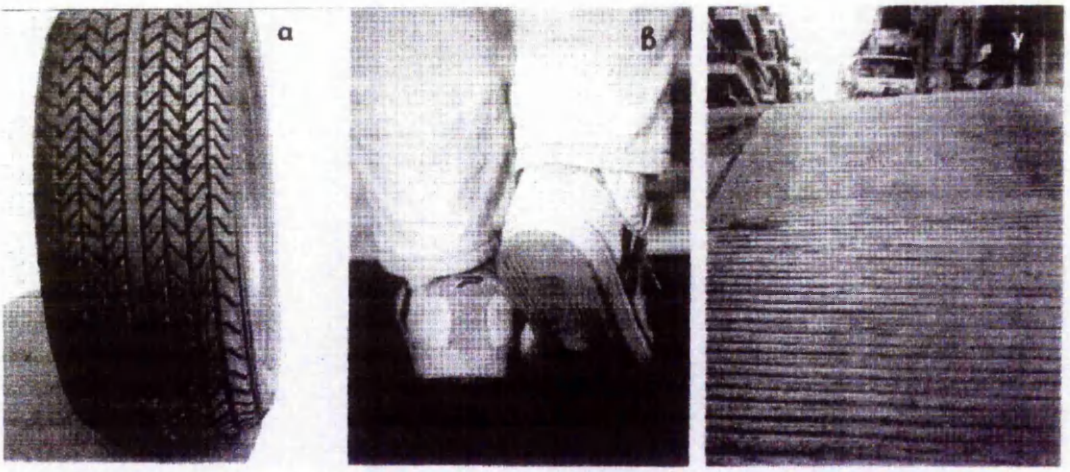


Εικ. 4 (Pict. 5)

Εικ. 5 (Pict. 6)

A heavy body will be moved easily, if, instead of pulling it, we put it on wheels or cylinders (rollers).





Εικ. 6 (Pict. 7)

In our various activities we sometimes aim to increase friction and ....



Εικ. 7 (Pict. 8)

sometimes to reduse it.

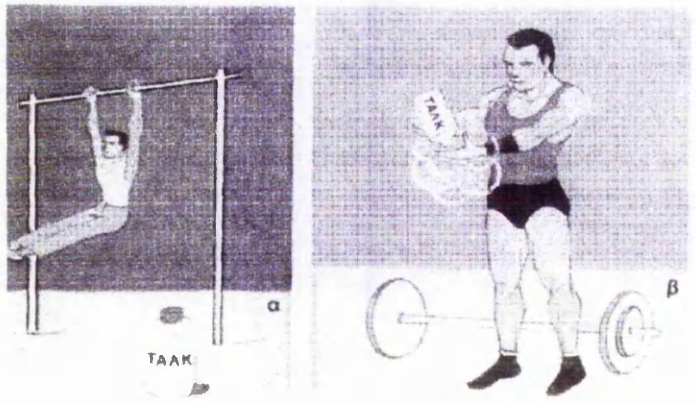
I check what I learn

● *Why do cars slip easily, when the roads are damp or covered with snow?*

● ***Find the right sentence.***

With wet hands I can easily : - Open a screwing bottle.
- Turn a door handle knob.
- Shape the clay.

Εικ. 8 (Pict. 9)



● *Some athletes, before the exercises put talc powder in their hands. Is there any reason?*

TEACHING UNIT: 4. The Force of Friction. (pp.65-66)

Aim

- The pupils should be introduced experimentally to the force of friction and examine the factors on which it depends.

Instructional Events -Pupils' Activities

The nature of the lesson inclines the teacher to place great emphasis on the need for experimental proof for each case referred in this unit.

With the experiments and the adequate guidance of the teacher, pupils can ascertain that the force of friction (a) does not depend on the area of the surface of contact of the body that is rubbed, (b) depends on the weight (pict. 3) of a body that is dragged on a surface and (c) depends on the kind of surfaces that come into contact (pict. 4).

It should be particularly stressed that the anomalies of the surfaces in picture 4 are under magnification, in order to become more vivid. In reality though, these irregularities are very small and many times untraceable by the eye.

The teacher should also ask the pupils to observe and to explain respectively pictures 5-7, which indicate possibilities for application of the force of friction in everyday life.

New word-concept

Friction

Clarification- supplementary knowledge

If a body moves on a horizontal level with constant velocity, then the force that provokes the movement has equal measure and opposite direction to the force of friction.

When a body slides, we call the friction that appears during the movement **sliding friction**, whilst when a body moves by rolling, we call it **rolling friction.**

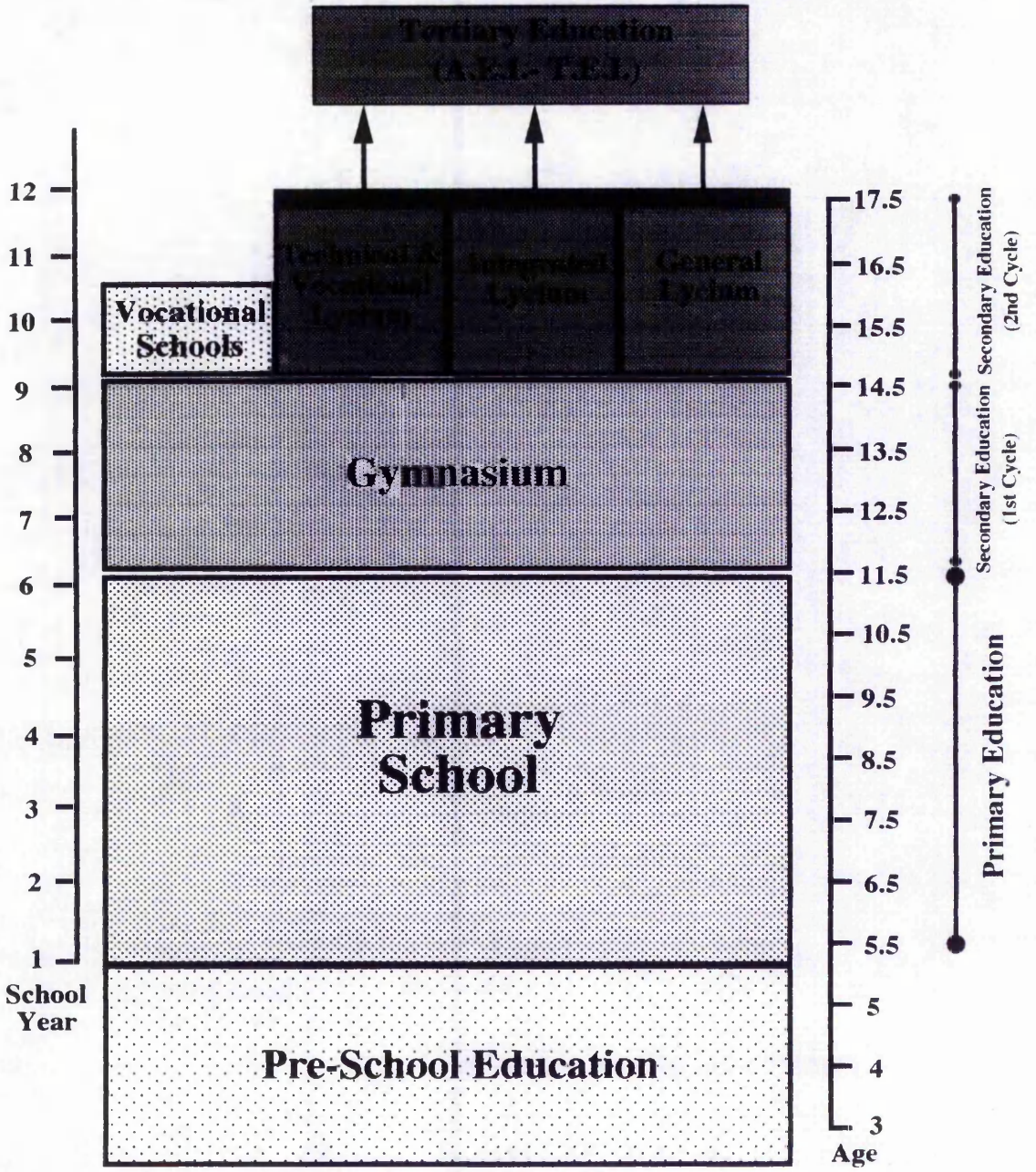
The force (needed) for the transportation of a body is less in the case of rolling friction instead (the case of) of sliding friction. So with the invention of wheel sliding movement was transformed to rolling movement in most of the constructions.

When we try to move a body with some force and it remains immovable, then an opposite force appears which we call **static friction.**

Answers to the questions and activities

1. Because friction is smaller on glass, the indication of the dynamometer (force meter) will be smaller too.
2. Because water that goes in between reduces friction and increases the sliding of vehicles.
3. The right sentence is "Shape the clay".
4. To increase friction, in order not to have slippery hands.

The Structure of the Greek Educational System



"*Apolyterion*" which may leed to Tertiary Education after "*Pan-hellenic Examinations*".

Source: **MBOUZAKIS, S. (Ed.)** (1990) *Comparative Education II: Theoretical Approaches and Foreign Educational Systems*, Athens, Gutenberg, p. 125.