STUDENTS' PREDICTIONS IN NOVEL SITUATIONS AND THE ROLE OF SELF-GENERATED ANALOGIES IN THEIR REASONING

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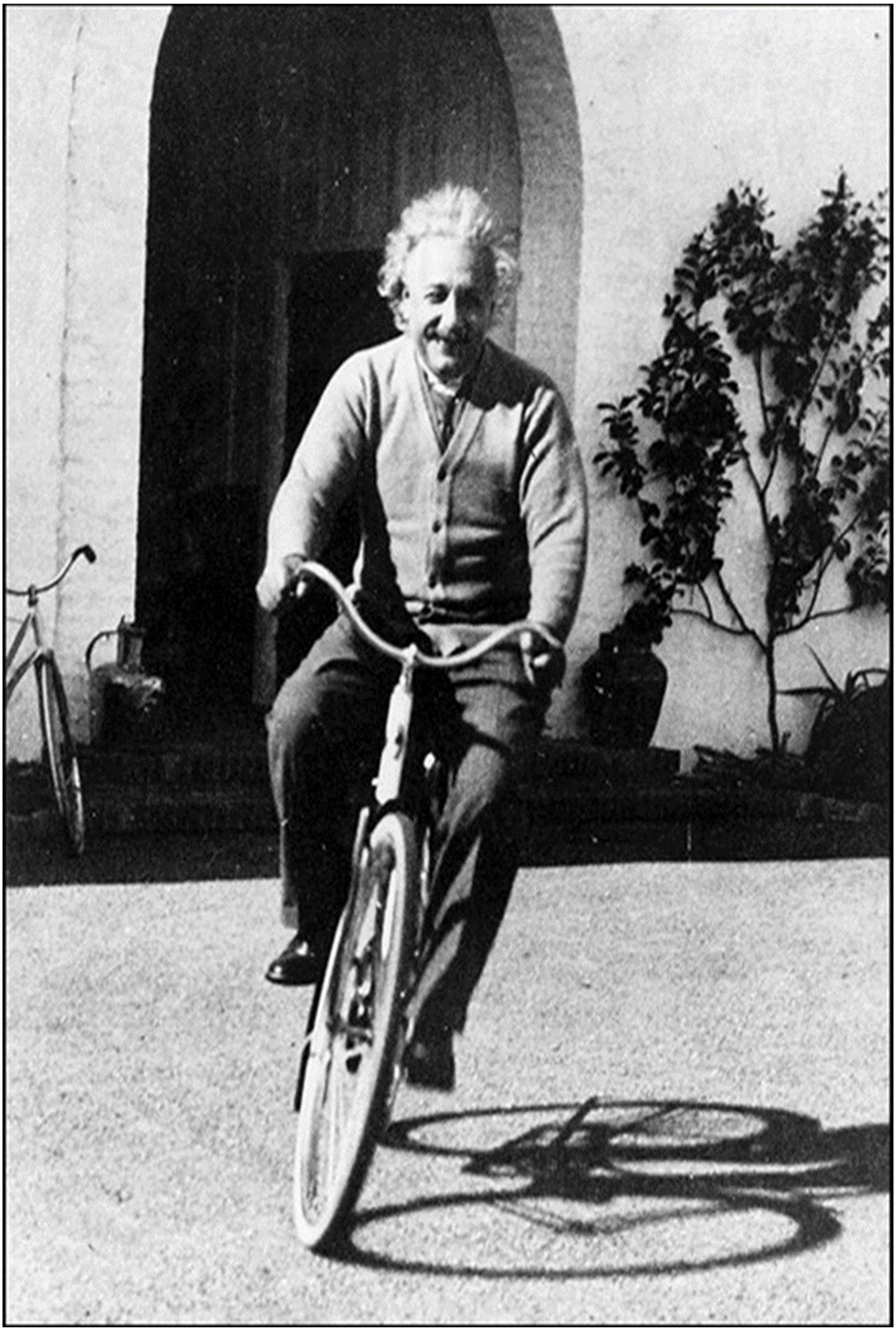

"The whole of science is the refinement of everyday thinking".

(Einstein, 1936, p.59)

The candidate confirms that the work submitted is his/her own, except where work which has formed part of jointly authored publications has been included. The contribution of the candidate and the other authors to this work has been explicitly indicated below. The candidate confirms that appropriate credit has been given within the thesis where reference has been made to the work of others.

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The photo in the second page shows Albert Einstein riding bicycle in front of Ben Meyer's House; Santa Barbara, California in 1933 (Leo Baeck Institute, 2012).

Abstract

This cross age study was designed to investigate students' predictions in novel situations and the role that self-generated analogies play in non-scientific reasoning. The study used a mixed method approach. Data was collected through the conduction of group interviews which were audio-tape recorded and additional data was collected through the use of written responses in the questionnaire. There were 37, 31, 29, 35 and 34 students recruited from Year 4, Year 6, Year 7, Year 9 and Year 11 (aged 9-10, 11-12, 12-13. 14-15 and 16-17 years) respectively from ten different schools in Greece. Students' responses were analysed to ascertain whether their predictions drew on the use of analogies, and if so, the nature of the analogies that they used and whether the ideas used in the explanations of their predictions could be understood from a p-prims or a misconception perspective.

The study found that students regularly make use of analogies, rather than scientific thinking in order to make their predictions. It also emerged that there were many similarities among students' predictions as well as the analogies they used to explain the latter. In many cases this students' non-scientific reasoning was based on their experiential knowledge which led them to make a prediction which is not compatible with the scientific view. However, according to the findings, there were cases in which analogical reasoning led some of them, more frequently the older (secondary education) ones, to make correct predictions.

The study suggests that teachers need to be more aware of the nature of the analogies used and how, and why, these analogies can, in many cases, lead students to make scientifically incorrect or correct predictions.

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Introduction (Chapter 1)

Analogies, as an instructional approach and as tool for reasoning have been of special interest to scientists, educators and philosophers ever since Aristotle. Analogy is a process used to compare structures between two domains and map relations from a familiar domain (base) to an unknown one (target) (Figure 1.1). The latter is the unfamiliar situation that is under examination whereas the former refers to the known situations which will form the basis to approach the target.

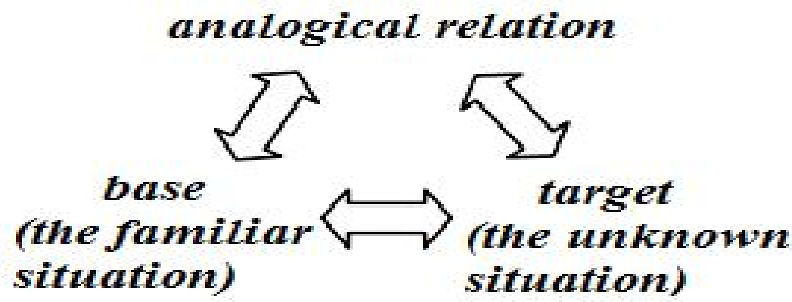


Figure 1.1 Basic elements involved in an analogy

Research in this area has consistently found that analogies play a significant role in adults' understanding and learning about natural phenomena (Gentner & Gentner, 1983; Spiro, Feltovich, Coulson & Anderson, 1989). Empirical evidence also suggests that analogies play a key role in children's learning as well (e.g., Dent & Rosenberg, 1990; Goswami, 1991). In Brown's (1989) words, "analogy as a learning mechanism is a crucial factor in knowledge acquisition at all ages" (p.370).

Using analogies can help people to understand and conceptualise a novel situation by allowing a comparison of a new problem's structural relation to that of a similar case stored in memory (Kim & Choi, 2003). Within a constructivist approach the learning process involves a search for similarities between the unfamiliar and the familiar, the new and that already known (Wittrock & Alesandrini, 1990).

The majority of studies which have addressed the use of analogies as an instructional tool for the facilitation of students' learning of science, have focused on the comprehension of analogies but not on how students could generate and use their own analogies in order to understand a new problem, phenomenon or situation. These studies have investigated analogies that are generated and provided by the researcher to the student and the latter is asked to use them in order to better understand a newly introduced concept (e.g., Gentner & Gentner, 1983; Summers, Kruger & Mant, 1998).

There is however a small number of more recent studies (e.g., Cheng & Brown, 2010) that have focused on the students' ability to spontaneously generate analogies, estimate their validity and refine them accordingly. These studies have explored whether students are able to use these analogies as a basis to develop new schemata or conceptual frames, as Duit, Roth, Komorek and Wilbers (2001) named this kind of new knowledge, and then use them to communicate ideas to others. The previous research has provided theories about analogy generation and an insight into the ways that analogies can be used in order to promote conceptual understanding of natural phenomena as expected at this level of science education.

Analogies, though, have another potentiality which could also contribute to the facilitation of students' learning of science but in a different sense. Wong (1993b) argued that each individual's unique prior knowledge influences the understanding of a new phenomenon and/or problem as well as the generation of analogy the individual uses to approach this new problem. Analogies could reveal students' intuitive knowledge which forms the basis for analogy construction and helps them to make predictions about a new problem. Therefore, analogies can be used to reveal students' beliefs and ideas underling the way they make predictions and explain novel situations.

With respect to the above, it could be argued that is timely to extend the use of analogies beyond their didactic purposes. Student-generated analogies can be used to investigate the extent to which they can serve as a tool for the facilitation of understanding novel situations as well as to what extent these self-generated analogies reflect students' knowledge. The present study investigates how students of different ages make predictions about novel situations. The basic assumption guiding this investigation is that students' predictions would be based upon the generation of analogies. It is plausible to assume that students make predictions by using analogies and there are numerous studies that provide evidence for this argument (e.g., Inagaki & Hatano, 1991, 2002; Vosniadou, Skopeliti & Ikospentaki, 2005). In turn, as several authors have argued (e.g., Wong, 1993b; Coll & Treagust, 2008), these student-generated analogies are based on students' views and ideas.

The basic aim is to compare the analogies students of different ages use in their predictions in order to reveal any similarities in their reasoning processes as well as whether students of different ages use the same or similar analogies. Such a comparison could be helpful in finding out if the analogies generated are based upon similar ideas/conceptions. This could also be helpful in shedding some light on the issue of the persistency and difficulty to change of those initial conceptions (or misconceptions) of students which have been identified in literature (e.g., Driver & Easley, 1978; McCloskey, 1983a). In other words, this study attempts to approach the issue of whether a misconception is a stored conceptual framework or could be better understood as resulting from an act of construction. In this sense, results from this present study may go some way to resolve the on-going debate over knowledge structure coherence (e.g., diSessa, Gillespie & Esterly, 2004; Elby, 2010).

Findings of this study are expected to have several benefits such as to contribute to cognitive developmental research by providing further details about how students, as they mature, make predictions about situations they have not considered before. This could show what ideas students employ in their analogies and how this already existing knowledge affects the process of familiarising with new situations and phenomena. Results could also contribute to the improvement of learning and teaching of science via analogical reasoning and comparisons by helping curriculum designers and teachers to use analogies more effectively inside the classroom avoiding at the same time the danger of a possible failure of analogies in promoting conceptual understanding (Duit et al., 2001) and the creation of more incorrect ideas.

This study is divided in five main chapters. Chapter two follows the Introduction (chapter one) and consists of a review the literature regarding students' ideas, analogies and reasoning. Its first part deals with students' conceptions which have been termed in the literature as misconceptions. A general introduction is given followed by a discussion on the criticism of the misconception approach, more particularly its seeming disparity with constructivism. The phenomenological primitives theory (diSessa, 1983) is reviewed as an alternative to the misconceptions perspective. The subsequent section discusses analogies. It starts by explaining more generally what analogies are. It discusses what the structure of an analogy is and how it functions and then it goes on to explain what are the differences between analogies, models, metaphors and examples but it also shows how these serve similar purposes and to what extent models, metaphors and examples can be seen as analogies. A discussion of access to analogies, their generation and use in order to reason about situations follows and it is in this section where the theoretical framework adopted for the analysis of the analogies expressed in this research is described. The chapter concludes with a review on recent studies in which student-generated analogies have been investigated. It discusses what has been found identifying at the same time the gap in the literature and promoting the suggestion of undertaking the present study.

The third chapter concerns methodological issues. It starts with a general review of the methodological approaches which have been used to investigate students' ideas and reasoning listing their advantages and disadvantages. The review is followed by the specific research problems and questions of the present study and a discussion on the research approach which was chosen to serve the purposes and meet the needs of these problems, offering a detailed look at each methodological issue, like the selection of the study sample along with the questioning approach chosen and the design of the research instrument. Within the same chapter, results from a pilot study are presented along with several problems that this phase indicated. For example, there were emergent issues related to the questioning approach chosen and the research instrument. A detailed discussion of these issues and the modifications made is presented. The chapter concludes with a discussion on ethical issues and the presentation of the method used for the data analysis and its validation technique.

Chapter four presents the data from the main research along with their analysis. Also, it gives emphasis to the most important results and it discusses key findings while Chapter five reviews the outcomes of the data analysis by addressing each one of the four research questions linking at the same time the outcomes with the existing literature. Chapter five highlights the main findings of the study and also shows how both the misconceptions and the p-prims approaches can be used for the interpretation of students' ideas and reasoning. It also discusses implications resulting from the findings indicating ways in which students' reasoning and self-generated analogies could be used for the facilitation of teaching and learning science. It concludes with a discussion regarding further research which could not only contribute to the development of our knowledge about students' ideas and reasoning but could also offer suggestions for the improvement of teaching science.

Chapter 2

Literature review

2.1 Introduction

Since the mid-1970s, research in science education has focused on identifying children's views and understanding across a wide range of ages as well as on an increasing range of science topics. The findings of this research suggest that students experience difficulties in understanding and learning science (e.g., Driver & Easley, 1978; McCloskey, 1983a; Garnett, Garnett, & Hackling, 1995). According to Novak (1988) this is because students might not be able to learn meaningfully which causes problems in relating what they are taught in science with other ideas they might hold, and with experiences from their surrounding environment.

Novak (2002) also argued that in order for a concept to be learnt, students should integrate new knowledge with knowledge already possessed in their cognitive structure. In other words meaningful learning involves students constructing and reconstructing their knowledge derived from their everyday experiences, phenomena they observe in their daily lives, new taught concepts, and other relevant knowledge (Tsai, 2000).

The connection between meaning and learning has been the subject of many studies in different areas of education (e.g., Osborne & Wittrock, 1983; Van Rossum & Schenk, 1984; Loughran, 2002). It has consistently been found that students come to their science lessons with varying conceptions, views about and explanations of the natural world. A great number of edited collections of papers, as well as some surveys, have reviewed students' views about several phenomena (e.g., Gilbert & Watts, 1983; Driver, Squires, Rushworth, & Wood-Robinson, 1994).

These students' views have been variously named in the literature as alternative frameworks (Driver & Easley, 1978), misconceptions (Fisher, 1983) and preconceptions (Ausubel, 1968; Ausubel, Novak & Hanesian, 1978; Anderson & Smith, 1983). In the following section misconceptions, or so called misconceptions, and p-prims as models of cognitive structures are reviewed and compared.

2.2 Misconceptions

Driver and Easley (1978) argued that the various terms used to describe students' ideas indicate the authors' philosophical position. Ausubel et al. (1968) used the term preconceptions describing children's views as having the status of isolated understandings that are characteristic of conceptual knowledge. Writers who use the term misconception (e.g., Helm, 1980) indicate a clear association of a mistaken view or an incorrectly assimilated theory with students' ideas. And those who accept the term alternative frameworks (e.g., Driver & Easley, 1978; Driver, 1981) indicate that students have created frameworks for understanding and interpreting their experience of the world around them. Although there are differences in the philosophical positions of these perspectives they do share some common features.

As Hammer (1996b) proposed, the common usage of these various terms (misconceptions, preconceptions and alternative frameworks) suggests that students' conceptions: a) are strongly held and stable structures, b) differ from experts' concepts, c) have a strong influence in students' understanding, 4) must be avoided or replaced towards scientific understanding. This set of characteristics might not be conventionally accepted. To illustrate, Hestenes, in a personal communication with Hammer, stated that these terms might be considered as simply referring only to the phenomenology of patterns in students' views which are inconsistent with scientific understanding (as cited in Hammer, 1996b). In this sense, the use of the term simply notes the existence of patterns. It does not attribute any cognitive structures or any explanations for the observed patterns in students' responses (Hammer, 1996b). However, as Hammer suggests, the aforementioned properties are consistent with the common way of using the terms misconceptions or alternative conceptions.

In this sense, the focus of the previous research was to identify the difficulties that students experience in understanding particular topics in science, report their misconceptions, and, in some cases, propose a way to deal with them. However, whilst such research produces an ever expanding catalogue of misconceptions, in some cases investigators have looked at the same misconception simply in another country. For example, Vosniadou and Brewer (1992) and Samarapungavan, Vosniadou and Brewer (1996) examined ideas about the shape of the Earth, moon and sun among students in the United States and India identifying similar, and in many cases, identical ideas. Although this could be a useful approach in revealing if students' ideas are context dependent, what the findings suggest is actually the contrary. Students, at least in these two different countries, did share the same views and this suggested the context independency of students' ideas (at least in terms of students' ideas in different countries).

Whilst there have been numerous studies into a wide range of students' misconceptions about concepts in physics and chemistry (see, Driver, Guesne & Tiberghien, 1985; Driver et al., 1994 for a brief review of these studies), Solomon (1993) has pointed out that there is a lack of a clear focus thus these studies do not seem to provide useful information to science teachers. Misconceptions seem to be, in many cases, content dependent, with each topic and even each type of problem requiring a different and sometimes unique strategy and/or approach to confront them (Tsai, 1999).

Helm and Novak (1983) argued that the term misconceptions (a term that is used throughout the present chapter in order to describe what was named in the literature as alternative conceptions, alternative frameworks, etc.) involves some connotations that seem not to be appropriate. The problem with the misconceptions perspective, as several researchers argue (see, Hammer, 1996a, b; Smith, diSessa, & Roschelle, 1994), is that it simply confuses the emergent knowledge in students' explanations with a reflection of constant conceptual frameworks; it perceives students' ideas as being stable and consistent (theory-like). As Smith, Blakeslee and Anderson (1993) argued, the misconceptions point of view overemphasizes the discontinuity between students' prior knowledge (the knowledge of the world that students bring to the learning of formal science) and scientists' conceptions. In other words, the position of misconceptions focuses only on how students' ideas conflict with scientific concepts, rather than providing any account of how students' ideas can be used productively and become resources for learning (Smith et al., 1993).

These properties of misconceptions were reflected in instructional approaches, for example the 'training between conflict' approach proposed by Stavy and Berkovitz (1980) and 'analogical teaching' strategies suggested by Schultz, Murray, Clement and Brown (1987). Most of these strategies are based upon one of the most influential studies on ways to deal with misconceptions held by students which is the early work concerning conceptual change theory (Posner, Strike, Hewson & Gertzog, 1982). In broad terms, conceptual change theory involves the active and rational replacement of existing ideas with the scientifically acceptable conceptions by the student.

The literature about conceptual change (see, Scott, Asoko & Driver, 1991 for a review) assumes that misconceptions either are formed phenomenologically when someone tries to understand and make sense of the physical environment, or are the social-cultural products of the use of scientific terms as metaphors used on a daily basis. According to this approach children's incorrect conceptions must be avoided, replaced or completely removed through the teaching process in order for students to understand experts' conceptions. Indeed, if assumed that this prior knowledge consists, to a great extent, of theory that is completely wrong (McCloskey, 1983a, b), then it is difficult to understand how it can play a creative and useful role in expertise; the theory must simply be somehow removed. Similarly, if there are fundamental differences between prior knowledge and expert scientific understanding, then learning and understanding of science should involve an extensive replacement of much of this intuition (Reiner, Slotta, Chi, & Resnick, 2001).

However, any approach that involves a large scale replacement of prior knowledge is fundamentally at odds with constructivism (Smith et al., 1993). If constructivism is accepted then there must be a sense in which the learning of science builds on existing knowledge. This is compatible with Einstein's view that "the whole of science is the refinement of everyday thinking" (Einstein, 1936, p. 59), which is of crucial importance in our daily life. As Abrahams and Reiss (2012) suggest, from an evolutionary perspective, the human brain has evolved in such a way as to help an individual to survive in the world rather than to necessarily understand it. Therefore, whilst there are many situations in which this kind of evolutionary knowledge, or what might be referred to as common sense, is compatible with the view of experts, studying in a scientific way the world is often at odds with this earlier form of knowledge. Thus, a constructivist view of learning and knowledge creation would suggest that students' prior ideas are not simply wrong, or as Dekkers and Thijs (1998) argued, there has to be a seed of correct and scientifically acceptable notions in these students' mistaken beliefs.

2.3 P-prims

There are approaches that have tried to deal with the aforementioned issues about students' ideas. Two alternative perspectives are proposed by Vosniadou (1992, 2002) and diSessa (1980, 1982, 1988, 1993) respectively. Although, Mayer (2002) thinks of these two perspectives as being different and conflicting, they both focus on the gradual development of students' conceptions deriving from intuition (Brown & Hammer, 2008). Vosniadou (1994) uses the term presuppositions for the fundamental conceptions that need to be evolved and claims that this kind of knowledge is more stable in comparison with diSessa's phenomenological primitives.

Investigating physics students' ideas about several concepts, diSessa (1981) found that they possessed conceptions which were extremely resistant to change. He identified these persistent preconceptions as phenomenological primitives (hereafter, p-prims). The core characteristics of p-prims are: a) they are fundamental and abstract cognitive mental structures, b) they are abstracted from common daily experiences of physical phenomena, c) they form the base for intuitive explanations of phenomena and d) they do not need further explanation.

DiSessa (1993) defined p-prims as being "hypothetical knowledge structures that act as primitive elements of cognitive mechanism - as atomic and isolated a mental structure as one can find" (p.112). Being atomic structures, p-prims are considered to be the elements of the knowledge system. The cognitive mechanism that diSessa proposed, that is based on these structures, seems to be basically connectionist thus, he argued that p-prims comprise an external level in addition to the internal one, implying that p-prims are activated according to their strength and moreover they can be connected with other p-prims. These connected elements could be activated by the mechanism diSessa described, the basic stages of which are:

a) P-prims are triggered by recognition. However, recognition does not literally mean that these primitives can be seen. As diSessa (1993) commented “it means being cued to an active state on the basis of perceived configurations, which are themselves previously activated knowledge structures” (p.112).

b) P-prims involve cuing (high or low) priorities. That is to say that the aforementioned activation of a p-prim takes place in a particular way, according to which, a transition of a p-prim is affected by other previously activated elements of knowledge. Thus, p-prims’ recognition occurs roughly in levels. In diSessa’s (1993) words “At the top are relatively conscious ideas and concepts that involve and are cued by lower level elements, down to sensory schemata or other low-level but less directly data-driven aspects of internal state” (p.112). Low or high cuing priority shows respectively a weaker or stronger connection between knowledge elements and structures that constitute the forerunners in the cuing sequence as well as the recognized one.

When students are placed in an environment involving some scientific concepts, they attempt to make connections between those concepts and the inputs received from the surroundings. P-prims can help students to establish relationships between scientific concepts, because, as their perspective suggests, they are like small pieces of knowledge or structures of qualitative reasoning that can facilitate students’ attempt to relate primary sensory data with relatively conscious notions (Masson & Legendre, 2008).

But how do p-prims affect the understanding of scientific notions? These preconceptions, that are responsible for affecting the understanding of science, are of such high priority as entailing “drastic reduction of priority or rearrangement of priority structure to allow expert-like understanding.” (diSessa, 1981, p.30). As diSessa’s (1982) research has shown, physics students were found to have a large number of these phenomenological primitives (diSessa provided a list of 31 p-prims related to mechanical concepts) deriving from what they see in the world around them. In turn, these experiences of phenomena from the surroundings become self-contained explanations of what they see. Many of these phenomenological formed ideas might become primitives. Subsequently they are perceived as being based upon other notions and they become elements of the cognitive mechanism with some of them not being explicitly recognized at all. The whole process affects the learning of physics.

P-prims lead students to forget and ignore whatever other principles they have been taught and this is the case even for students that study physics as the work of diSessa (1982) has shown. Some ideas which have been rooted in students’ way of thinking and reasoning for many years, in their own way of seeing and perceiving phenomena in their daily life, may have the potential to be stronger than physics laws that they have learned (Raduta, 2006).

Cheng and Brown (2010) suggest that the difference between the misconception perspective and that of p-prims is simply a matter of different modelling languages used to represent students' ideas. However, the two approaches differ a lot with respect to what the science teacher may find in the research of students' ideas and how these ideas could be developed towards the scientific way of thinking. Hammer (1996b), comparing the two different approaches, clearly articulated the differences concerning the pedagogical approaches used in order to deal with p-prims versus misconceptions.

As it is mentioned above, based upon the misconceptions perspective, a science teacher sees students' ideas as inherently inconsistent with the scientific knowledge. On the other hand, using the p-prims perspective, a teacher sees children's conceptions as being elements that could contribute to an expert way of thinking (Hammer, 1996b). In Hammer's words "The principal practical significance for a teacher is that the former implies the task of dismantling and replacing prior knowledge, whereas the latter suggests the task of modifying the organization and use of prior knowledge" (p.117).

Using the latter view, students' explanations of phenomena are not understood as a reflection of systematic and coherent frameworks. Instead their views could be seen as spontaneous constructions deriving from prior knowledge and experiences. These views are generated when students try to explain a new situation. As Cheng and Brown (2010) suggest, intuitive and sub-conceptual features of knowledge appears to be functioning when an individual tries to explain and understand a phenomenon. Although there is recent research that supports and provides evidence for this statement (e.g., Inagaki & Hatano, 2002, Cheng & Brown, 2010, Vosniadou, 2012) this is not a new idea. In a similar manner, many years ago, Hancock (1940) had argued that misconceptions could be considered not as coherent frameworks but as the result of faulty reasoning. Thus, it is plausible to think that misconceptions are spontaneously created when students are presented with a new situation that they have not considered before. Indeed, as Rowlands, Graham, Berry, and McWiliam (2005) have argued, researching students' reasoning in a specific novel situation should reveal students' pre-formed ideas which could constitute the source of misconceptions, or the instruments that generate them.

For instance, in one popular demonstration of misconceptions, children were asked to explain the seasonal cycle (why it is colder in the winter than in summer). Looking at the data in the literature it could be argued that the dominant explanation that students at different ages provide about this phenomenon is that it is hotter in summer because the Earth is closer to the sun (figure 1).

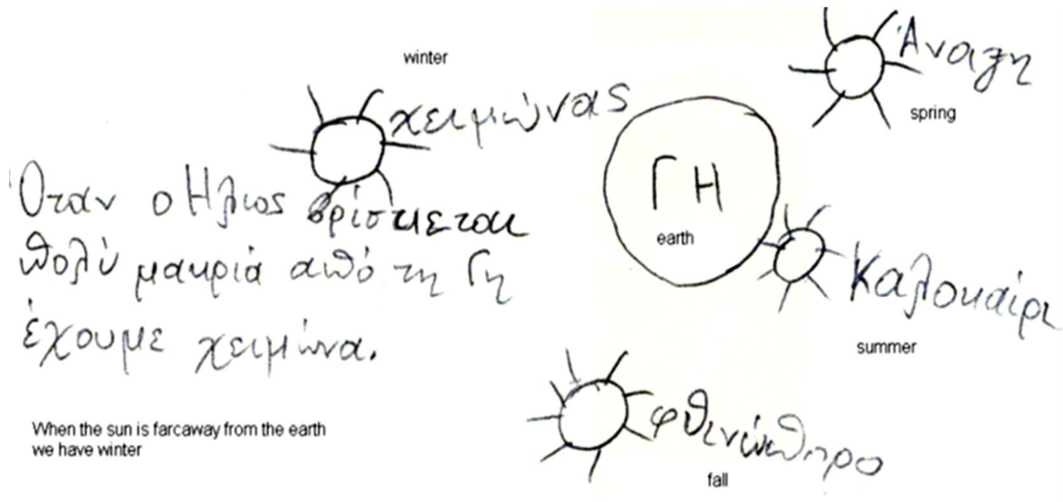


Figure 2.1.1 A drawing of students' initial representations about the cause of seasonal changes,

Source: Pilatou et al. (2008), page 6.

It is difficult to regard this response as a misconception because it might be the case that the students in this study had never previously thought about this phenomenon before being asked and certainly did not hold any strong preconceptions about it meaning that it is unlikely to have been a part of the students' knowledge system. A more plausible interpretation is that students constructed that idea spontaneously at the moment when being asked in order to provide an explanation.

It is possible for students to reason and explain this phenomenon using the idea of the axis tilt. However, research has shown that students believe that due to the tilt, one hemisphere is pushed closer to the sun (Osborne, Wadsworth, Black & Meadows, 1994). Technically such understanding and interpretation is accurate and indeed hemispheres are slightly closer or further because of the tilt. Nevertheless this is not the principal reason as to why there are seasons on Earth. Although in this case students are aware of the scientific explanation, it seems that the closer means stronger p-prim is of highly reliability priority. It could be fruitful to investigate if this priority is apparent in different aged students' analogical reasoning.

As diSessa (1993) argued phenomenological abstractions can be self-explanatory schemata. That is to say that something happens simply because this is how things are. In the case of closer means stronger p-prim it might be derived from a number of phenomena experienced in day-to-day life. For example, fireplaces are hotter the closer one gets to them, a light is brighter the closer one is to it and music is louder the closer one gets to a speaker.

This raises the question of whether it is possible to ascertain which of the two perspectives best reflects the origin of students' ideas. Whilst Solomon (1993) argued that an effort to understand how an individual combines the inputs and draws upon them to construct knowledge is unlikely to be something that could be empirically tested it might be possible to test whether students' ideas (those reported as misconceptions) constitute a way of combining these inputs (their reasoning processes) rather than being part of their knowledge system.

The latter can be done by looking at the way that students reason when they confront a novel situation. Given that Rowlands et al. (2005) claim that misconceptions are spontaneous, in the sense of their being created firstly when an individual first encounters a novel situation, it would be fruitful to examine how students' explain a situation that they have never thought of before and therefore could not possibly have a pre-existing explanation for.

What follows is a discussion about how analogies can play an important role in students' predictions and explanations in novel situations.

2.4 What an analogy is

Whether or not we talk of discovery or of invention, analogy is inevitable in human thought, because we come to new things in science with what tools we have, which is how we have learned to think, and above all how we have learned to think about the relatedness of things. The only way to come into something new is on the basis of the familiar and the old-fashioned even if this is described as a misconception, p-prims or similar term. As Oppenheimer (1956) argued, we cannot learn to be surprised or astonished at something unless we have a view of how it ought to be; and that view is almost certainly an analogy.

According to Vosniadou (1989) analogy is one of the processes recognized by scientists, psychologists and philosophers (Hesse, 1966; Gentner, 1983; Clement, 1987), as being an effective mechanism for mobilizing prior knowledge in order to acquire and explain radically new information. Thinking by using analogies is a core mechanism in everyday problem solving; in Polya's (1957) words "analogy pervades all our thinking, our everyday speech and our trivial conclusions as well as artistic ways of expression and the highest scientific achievements" (p.37).

In an attempt to be engaged in an in depth discussion of almost anything that is to be investigated, what is needed is an employment of the relative language. Thus, what follows in this part is a discussion of the basic terms like analogy, base, target, attribute, relations, domain and mapping used in the literature.

The literature about analogies and related areas, including models, displays a wide range of complexities about the use of the term analogy. What is needed is a consideration of what an analogy is and how it is perceived for the needs of the present study.

The term analogy is given different meanings with a certain overlap in literature. Analogies, metaphors, models and examples are viewed as having many similarities and there are authors who have used these terms interchangeably whereas others have different concepts in mind when they employ these terms (Duit, 1991).

Concerning the structure of analogies, their form is similar to similes/metaphors or the structure of the former is quite similar with the latter, albeit there are some minor differences between the use of these terms (Gentner, Bowdle, Wolff & Boronat, 2001). Generally, analogies have two components: the base and the target. The latter is the unfamiliar situation that is under examination whereas the former refers to the known or familiar situations which will form the basis to approach the target (Clement & Gentner, 1991; Spellman & Holyoak, 1996).

2.4.1 The nature of analogy

As Driver and Bell (1986) put it an analogy consists of a target about which new knowledge is desired to be acquired, a base which is a situation that seems to be already understood and a relation that maps elements from the former to the latter case. In this sense, what analogy can do is to help students make connections between their pre-existing knowledge and the new concepts that are being taught. In this sense, new knowledge could be produced and unknown situations might be perceived by using analogies in a productive way.

According to Vosniadou (1989) this productive use of analogies is usually based upon the identification of some similarity in properties of the source and the target not on their explanatory structure and this is because there is not any knowledge of the relevant structure of the target. In a similar vein, Hesse (1967) commented that similar explanatory structures would not lead to the development of new knowledge as the identification of similarities in explanatory structures presupposes that there is an available theory for both the target and the base.

In Gentner's (1983) words "an analogy is an assertion that a relational structure that normally applies in one domain can be applied in another domain" (p.156). To illustrate this point it would be better to examine the example of using the solar system as analogy for the planetary model of the atomic structure, introduced by Rutherford (1911). Presuming that students have already understood the structure of the solar system they can use this knowledge in order to learn about the structure of atoms.

Students should already know that most of the celestial objects in our solar system are relatively small masses in comparison to the Sun. Moreover, they should have the prior knowledge that planets revolve around the Sun in orbits that are almost circular. These knowledge elements should be related and compared with the tiny parts (electrons) that revolve in shells of various radii around the centre of the atom where the massive nucleus is placed. So, in this case the base concept is the already known one about the structure of the solar system. The target concept is the structure of the atom that is to be learned.

Each of the two domains has certain features or attributes which can be mapped as being quite similar. In this example, planets and electrons revolve around a massive mass placed in the centre. These functional similarities can become relational similarities. However, the base has also some features that are not similar and moreover they are not expected to be mapped. For instance some planets, like the Earth, have moons whereas there are no other tiny orbiting bodies revolving around electrons have and also, the Sun, unlike atomic nuclei, is hot.

The analogy in the latter example is based upon the comparison of two situations, which belong to fundamentally different conceptual domains. But they do share a similar explanatory structure. The properties of the sun, nucleus, electrons and planets are fundamentally different but there are many structural aspects, like these described above, that are very similar and can be transferred from the one domain to the other. These types of analogies are named by Vosniadou (1989) between-domain analogies.

In other situations, there are analogical comparisons based upon items that are parts of the same, or very similar, conceptual domains. A typical example for such an analogical reasoning is proposed by Kedar-Cabelli (1985). Given as a base concept a Styrofoam cup which can be used to drink hot liquids it is possibly for the individual to reason analogically and come to the conclusion that a ceramic mug enables one to drink hot liquids as well. This type of analogical comparisons is described by Vosniadou (1989) as within-domain analogies. There are some theories that consider within-domain comparisons as literal similarities rather than as analogies. A representative one proposed by Gentner (1988) is examined below.

Although there are some differences between these types of analogical reasoning, the distinction between between-domain and within-domain analogical reasoning is not a dichotomous one. As Vosniadou (1989) argued the two different types share similar characteristics to different degrees. They both represent a continuum from reasoning that involves items of the same concept (such as examples described further in this chapter) to comparisons that are based upon different and irrelevant domains.

The recognition of the similarities and the transfer of knowledge between the two systems are characterised by Gick and Holyoak (1983) as a process of mapping information from a base situation to the target domain. In accordance with this perspective Gentner (1983) proposed a theory for analogy creation and interpretation. In Gentner's words, the basic principle in this theory is that "a relational structure that normally applies in one domain can be applied in another domain" (p.156). It is named the structure mapping theory and as Duit (1991) commented this theory shares many characteristics with theories of propositional networks (like that proposed by Rumelhart & Ortony, 1977). Also, there are many major similarities between structure mapping theory and the formal definition that Duit provided for analogy.

As Atkins (2004) pointed out, this model was successful in interpreting and predicting analogies and could be used productively in interpreting student-generated analogies in science. The mapping of knowledge from the base domain to the target one conveys "that a system of relations that holds among the base objects also holds among the target objects (…) In interpreting an analogy, people seek to put the objects of the base in one-to-one correspondence with the objects in the target so as to obtain the maximum structural match" (Gentner, 1989).

The structure mapping theory proposes a set of procedures and rules which can be used in order to understand the creation of an analogy. Starting from an analogy according to which a T situation (the target one) is like the B one, which is the base, there is a mapping of B onto T object nodes. As Gentner (1983) described it, assuming that the representation of the target domain has object nodes like t_1,, t_2,…,t_m and that the domain B can be represented in terms of object nodes b_1, b_2, . . . ,b_i, and predicates such as A, R, R ' the analogy maps the b_i onto the t_i :

$$M: b_i \rightarrow t_i$$

The set of the rules for the mapping procedure presented in Gentner's (1983) work are:

1. Discard attributes of objects:

$$A(b_i)] \text{ - - / - -> } A[(t_i)$$

2. Try to preserve relations between objects:

$R(b_i,b_f)]$ - - - -> $R(t_i,t_f)]$,

3. (The Systematicity Principle). To decide which relations are preserved, choose systems of relations:

$R'(R_1,(b_i, b_j), R_2(b_k, b_i)]$- - - - >

$[R'(R_1(t_i, t_f), R_2(t_k, t_i)$.

The procedures are based upon the features and properties of the knowledge representation. In other words what suggests the basis for analogical mapping are the relationships between terms or objects. This basis of analogical comparison can be used in order to judge the soundness of analogies and this can be done by evaluating the degree of the similarities between the two domains. An example could be the comparison of a tire with a shoe. As Gentner (1988) commented the comparison of a tire with a shoe founded upon the fact that both can be used to cover terrain would be more appropriate than an analogy referring to their colour (both are made of rubber which is usually black). Nevertheless, regarding the example of the tire and shoe, it is worth stressing that the use of analogies could be context dependent. In other words, the appropriate similarities to be drawn between the base and the target could depend on the context of the problem which is under examination (Carbonell, 1986). In this particular example, how the temperature of a shoe and a tire placed in the sun changes might better be understood on the basis that both are made of rubber that is usually black.

Returning back to Gentner (1983), it should be noted here that his structure mapping theory has received a great deal of attention and support. Despite the fact that there are other, alternative theories that differ in emphasis (e.g., Winston, 1981; Burstein, 1983; Carbonell, 1983) all of them would agree to the core element of one-to-one mapping of objects, with transfer of predicates. Many other researchers indeed share the same concept of analogy as being a process of mapping and in many studies the precise structure-mapping theory has been used (e.g., Rumelhart & Norman, 1981; Gick & Holoyak, 1983; Reed, 1984;).

The aforementioned rules for the creation of analogies, as well as the type of the shared versus non-shared predicates, can be used to make distinctions between analogies and other kinds of domain comparisons. Gentner (1983) makes a distinction between four kinds of similarities:

1) Literal similarity. Object attributes and relational predicates are mapped.

2) Relational abstraction. In this case there are not concrete properties of objects not being used in the mapping. Abstract relational structures of the base situation are mapped.

3) Mere- appearance match. Mainly object descriptions are mapped.

4) Analogy. Chiefly relational predicates are mapped and very few object attributes.

Gentner made a distinction between descriptive properties of objects (object attributes) and relations, while also claiming that an analogy implies that there should be only similarities in relations without any similarities in object attributes. Vosniadou (1989) argued that Gentner's theory pays more attention to static similarity statements such as that about the structure of the atoms described above. Considering simply the analogies and not the process of reasoning, there are definitional implications between within-domain and between-domain analogies but analogical reasoning cannot be different. Reasoning by analogies can involve items that belong to the same fundamental domain employing the transfer of an explanatory structure from one item to the other or to items that belong to different categories.

2.4.2 Metaphors and analogies

According to Black's (1979) description of metaphors:

> A metaphorical statement appears to be perversely asserting something to be what is plainly not. . . . But such 'absurdity' and 'falsity' are of the essence: in their absence, we should have no metaphor but merely a literal utterance. (p.21)

The use of a metaphor entails a 'hidden' comparison. In other words, a metaphor compares but this is done implicitly.

Moreover, Duit (1991) argues that there is an element of surprise in metaphors. In this sense metaphors are statements where the basis of the comparisons has to be created or revealed. It is also possible to consider a metaphor as an identification of dissimilarities so as to motivate the individual to look for similarities. This process provides a degree of imagination and this can help the addressees of the metaphor to create in their mind a representation of abstract ideas (Davidson, 1976; Miller, 1979).

A metaphor highlights relational qualities or characteristics that do not coincide in the two situations in comparison and this is not done explicitly. In contrast an analogy explicitly compares the structures of the two domains. It is generally accepted that analogy involves the recognition and transfer of knowledge from a known system, usually called the source or the base, to a new and relatively unknown system, the target.

Therefore metaphors and analogies serve similar purposes. Both are used to highlight similarities and comparisons but this is done in a different way. They do differ but only to a slight degree, they are not a dichotomy. Metaphors can be seen as analogies and analogies may be seen as metaphors (Duit, 1991).

2.4.3 Analogies and models

The distinctions between the aforementioned kinds of similarities are not very strict. For example, although Gentner (1983) distinguished literal similarities between analogies, he argued that they are not a dichotomy. As mentioned above, literal similarities share many object characteristics and relational similarities. They can be considered as replicas used to represent the real thing, which, as an object, cannot easily be studied and examined closely and thoroughly. Typical examples could be models used for educational purposes like torsos showing the internal organs, skeletons used to represent human's bones or up-scaled models of insects. In this case, there is no need for the one to be considered as a metaphor and of course, such a model could not be considered as an analogy for the real thing.

There is a variety of purposes and many different notions in the way that the term model has been used in the literature and not even researchers are strictly consistent with the definition given in this term (Duit, 1991). Nevertheless, there is some agreement in what models have to do and are related with the structural mapping of two different domains as described above. Models often represent parts of structures of the target situation. Thus, models can be the basis for analogies in the sense that a model becomes a model through the analogy relation between the target and the base domain. The term model is not only used for the analogical relation of the two domains but also, as Leatherdale (1974) pointed out, for the analogue domain. This way, the terms analogy and model are regularly used interchangeably (Duit, 1991). A typical example could be the flowing water analogy used to represent electric circuits which is frequently called the water model (Gentner & Gentner, 1983).

However, considering that a model could be used as an analogy the distinction might become more complicated. An example could be the ball-and-stick models which are often used by chemists to represent chemical compounds of substances like the H_2O molecule (Fogwill, 2010). The model is a replica of the real water molecule and it has three atoms and bonds between them as the real molecule does. It also represents accurately the relative positions of the atoms ensuring that the bond angles between the two hydrogen atoms and the oxygen atom are compatible with the scientific measurements.

Accepting this model as an analogy for the real molecule and taking into consideration that properties of the molecules can be measured by using the current technology, this model could be classified as an unscientific analogy basing upon the view that a scientific “model is a research tool which is used to obtain information about a target which cannot be observed or measured directly” (van Driel & Verloop, 1999, p. 1142). However, students are not able to use the current technology to take measurements of molecular properties and thus, this model is scientific, for it gives them the opportunity to understand and visualise something that cannot be seen. This is something common in scientific thinking. Molecular models have been used, in an analogical way, in the development of many revolutionary theories molecular models. For instance, the Nobel prized Watson and Crick used such an analogy in order to represent the double helix model for DNA. In addition, Wilbers and Duit (2006) argued that molecular models have become a fundamental tool so as to study chemistry and they gave several other examples of pioneering scientists that used this analogical process like Dalton, Pauling and Kekule.

Moreover, this model could not be classified as an analogy because, according to Zeitoun (1984), the ball-and-stick model and the real molecule both “belong to the same schema” (p. 110). By schema here it is meant the conceptual frame that represents what is already known. As Fogwill (2010) argued, the latter can be plausible for someone with a canonical knowledge. However, this can be reasonable for children only if they have been taught about the water molecule and its chemical structure has been internalised by using the analogy of the ball-and-stick model.

2.4.4 Examples and analogies

Both analogies and examples are used to make the unfamiliar familiar. Glynn, Britton, Semrud-Clikeman and Muth, (1989) claimed that it is possible to clearly make a distinction between analogies and examples. In their opinion, “an example is an instance of a concept not a comparison between similar features of two concepts” (Glynn et al., 1989, p.385). In contrast, Duit (1991) argued that examples can be used as analogies or can be viewed in such a way. In an attempt to relate more examples with a taught or a given concept people usually make statements that are based upon comparisons and these can be seen as analogies. In addition examples that are provided to represent or describe the features of a concept can be viewed and interpreted as analogical relations.

The table below presents a review of the terms discussed in this subsection. These are used to describe what an analogy is.

Signifier	*Definition*	*Example*
Target	The concept and/or the situation which is attempted to be explained	The atomic structure in the case of the planetary model/analogy. The Ceramic mug in Kedar-Cabelli (1985) example.
Base Source	The situation and/or the concept that is used in order to facilitate the explanation of the target	The prior knowledge about the Solar System that has the potentiality to be used in the understanding of the atomic structure. The Styrofoam cup which can be used in the reasoning about the ceramic mug.
Explanatory structures Similarities Relational similarities Relational predicates Functional similarities	Features that indicate analogous relationships	A model of the Solar system and an atomic model shows that both are spherical bodies revolving around a central mass. Both the ceramic mug and the Styrofoam cup are graspable.
Features Attributes	Physical attributes of objects	Both the atomic model and the Solar System have a mass placed in the centre. The Styrofoam cup and the ceramic mug have a conical shape.

Domains Items Situations	The object which are to be compared	The atom and the Solar system. The ceramic mug and the Styrofoam cup.
Within-domain analogies	Comparisons between domains that share strong surface similarities.	The Styrofoam cup and ceramic mug are similar in terms of their shape.
Between-domain analogies	Comparisons between entities that have similar explanatory structures.	The conceptualization of the Solar System could facilitate to picture the atomic structure (and vice versa).
Mapping process	The identification of similarities between the base and the target.	Electrons of the atom revolving around the nucleus are like planets orbiting the sun. The similar shape of the ceramic mug and the Styrofoam cup implies that both might be graspable.

Table 2.1.2 Terms used in analogy description.

Cosgrove (1995) used the metaphor of opening black boxes, in order to emphasize the effectiveness of analogies in helping students to develop understanding of difficult concepts. Therefore, whether something is an analogy or literal similarity and how one can name it seems to be less relevant than the analogical reasoning as a process that is employed in an attempt to perceive and explain a novel situation. What is taken into consideration in designing this present research is if students involve in their explanation the transfer of an explanatory structure or a feature from one situation to another regardless of how this process is called (a model, an example or an analogy). More particularly, it is attempted to look for any similarities in the situations that students use on order to facilitate the understanding and the explanation of the novel situation.

2.5 Access to analogies

The structure mapping approach is a well-supported theory and can be used to describe the rules by which people explain and reason basing upon an analogy once it is accessed. But how an analogy is accessed is a different matter. As Gentner and Landers (2005) defined it, access is the act of matching the given situation (target) with the base situation in memory. To put it differently, access concerns the process of the target reminding a student of an analogous situation in his memory.

The spontaneous access to analogies has been found to be influenced by a number of different factors (Christensen & Schunn, 2005). As Gentner and Landers (1985) argued the knowledge about how people notice and access analogies is limited and it is difficult to get information about this particular process. Also, as Christensen and Schunn (2005) noted, attempting to measure spontaneous access entails methodological problems which might explain why knowledge in this area is limited.

What are the influences that can be said to cause the individual to spontaneously think of some piece of prior and stored knowledge when confronted with a problem or a new situation? A number of factors have been found to influence spontaneous analogical access.

One of the dominant approaches about what affects the analogical access comes from the area of artificial intelligence. This approach suggests that access takes place through higher-order relations or other causal relations (Winston, 1981; Schank, 1982; Carbonell, 1983). Schank (1982) proposed the notion of causal indexing to represent this particular view of accessing via causal relations. The core idea behind causal indexing is that people access prior knowledge in memory by combining predictive causal structures and the problem or the situation presented. Therefore, as Gentner and Landers (1985) commented, causal indexing indicates that the spontaneous accessibility of an analogy is controlled by the same factors and principles that determine the degree to which analogy is effective, predictive and inferentially useful. In other words access to an analogy is closely related to the extent that the target and base share causal relations. This position bears a resemblance to the principle of systematicity (Gentner, 1983) described above.

Nevertheless, findings from psychological research suggest that this might not be the case; access does not seem to follow high-order and causal relations. Gick and Holyak (1980) conducted a research to investigate students' ability to solve a very difficult problem. Students read some material related to the problem before receiving the original problem. This material was analogous with the problem students were asked to solve and moreover, it comprised the solution. Although students were able to solve the problem after being told about the analogy, only around the 30% of them spontaneously noticed the analogy, notwithstanding that they received the problem immediately after reading the material. These results are in agreement with a similar research carried out by Reed, Ernst and Banerji (1974).

Along this line, Anolli, Antonietti, Crisafulli and Cantoia (2001) reviewing the studies related to analogical access supported the outcomes of Gick and Holyak's (1980) study. Anolli et al. pointed out that to be giving students a ready-made analogous source prior to showing the original problems hardly leads to analogical reasoning and mapping of similarities. This could happen only if the students are given explicit instructions to use the source to solve the problem. Such findings dispute the accessibility of analogies by sharing high-order causal structure and show that an analogy can be difficult to be accessed and noticed even when it is obvious that it could solve the problem.

Also, Ross (1984) concluded that an analogy is more easily accessed if the context of the problem asked to be solved resembles the context in which students have learned anything related to this problem. Other studies have shown that the presence of noticeable superficial similarities gives rise to spontaneous access (e.g., Holyoak & Koh, 1987; Gentner, Rattermann, & Forbus, 1993). The aforementioned outcomes suggest that analogical access is not influenced simply by causal structure but on the contrary it is affected by overall similarity.

2.6 Reasoning by analogies

Along with investigating ways of accessing an analogy, several studies have indicated that the use of analogies is of crucial importance in approaching new, unknown situations.

Clement (1981) provided evidence about the use of analogies by experts when they attempt to resolve any conceptual difficulties they confront during problem solving. There is evidence from historical studies (Dreistadt, 1968) and field studies (Knorr-Certina, 1981) that experts use analogies as a way of reasoning. Several authors argued that analogical reasoning is an important source of innovation in scientists' work and can suggest an effective technique for solving problems (e.g., Clement, 1987).

A more direct line of evidence is the report of the use of analogy by scientists in the development of a new theory. As the well-known astronomer Johannes Kepler wrote: "And I cherish more than anything else the Analogies, my most trustworthy masters. They know all the secrets of Nature and they ought to be least neglected in Geometry" (Polya, 1973, p.12). Also, the nuclear physicist Sheldon Glashow (1980), who was awarded the 1979 Nobel Prize, made a reference to the use of analogies developing the unified weak and electromagnetic interactions theory:

> I was led to the group SUX2 x U(1) by analogy with the approximate isospin-hypercharge group which characterises strong interactions(…)Part of the motivation for introducing a fourth quark was based on our mistaken notions of hadron spectroscopy. But we also wished to enforce an analogy between the weak leptonic current and the weak hadronic current ... (p. 1321-1322)

The aforementioned kinds of remarks are strongly suggestive of the function of analogies as tools of thought that can facilitate the understanding of a novel situation. The use of analogies can facilitate people's understanding of a new problem by allowing them to make comparisons between the unknown problem's relational structure with a familiar one (Oppenheimer, 1956). In agreement with this statement, Wong (1993a) pointed out that the perception of the familiar in new situations is something unavoidable. If this was not true, then all the experiences would seem to be useless, novel and strange for the individual. The ability to recognize similarities and identify the differences between situations is a core characteristic of the human mind. Differentiation and recognition is achieved through the processes of analogical reasoning by which experience of what people see is related to what is already known.

> You argue that a man cannot enquire about that which he does not know; for if he knows, he has no need to enquire; and if not, he cannot; for he does not know the very subject about which he is to enquire. (Plato, 380 B.C.E., 2005, p.68)

Following, that understanding is guided, affected and constrained by elements of prior knowledge. Based on analogies, understanding of an unfamiliar novel situation might be constructed by comparing and differentiating between this unfamiliar situation and more familiar aspects of understanding. These pieces of evidence suggest that analogies are fundamental to the way in which adults understand and learn about novel situations and/or experiences. Indeed, children do use analogies and there is numerous evidence that students reason in this way. For instance, Dunbar (2001) found that when students explain their ideas to others they draw upon analogies.

Due to the importance of analogies in learning and understanding, students' analogical development and reasoning attracted psychologists' and science education researchers' (Gentner, 1983, 2003; Glynn, 1994, 2008) interest over the last 20-25 years. Much of the research however, has focused on analogies generated by instructors or researchers in order to test their effectiveness as a teaching tool in science, facilitating students' learning of concepts in this way (Harrison & Treagust, 2000; McSharry & Jones, 2000). In a similar vein, other researchers provided students with an analogous situation to be used in order to understand the unfamiliar one and explored the conditions under which analogical reasoning can lead to the successful resolution of a class of problems.

In the context of schools, science teaching follows a well-known path: the concepts which need to be taught are presented; problems based upon these concepts are provided; the solution to the problems is found using the concepts that have been taught (Wong, 1993a). There is a close connection between the problem and the concepts needed for the solution when an individual needs to determine which elements of knowledge should be applied. The same pattern was followed in research on studies about the use of analogies outside classroom (e.g., Yelamarthi, Ramachandran, Mawasha, & Rowley, 2006). The focus of these past studies was students' interpretation of analogies. This reflects a model of education according to which students receive and interpret knowledge from the teacher without contributing to their own knowledge development as well as to the instruction process.

More attention has been paid, therefore, to analogies generated by a researcher or a teacher that a student then tries to interpret as a means of facilitating the learning of science by using this particular instructional tool. Indeed, such research identifies how students can learn from analogies and provides important insights concerning the process as well as the conditions that make easier and impede analogical transfer.

On the other hand, as Duit et al. (2001) commented, there is an abundance of empirical evidence, suggesting that the use of analogies might not always be effective in promoting conceptual understanding. A number of factors are found to affect students' capability of understanding via analogies. The most important factors seem to be related to the way that the source is presented to the subjects and the different ways students use analogies. For instance, if the conditions of the experiment emphasize a rich encoding (i.e., the process of comparing two situations and reaching a conclusion on its basis) and structural information of the source, then access and use of analogies is improved (Dunbar, 2001). If relational similarities (matching processes and functions between the elements of the base and the target that are considered to be similar) are explicitly stressed, conceptual understanding of the base and the target is facilitated (Clement, Mawby & Giles, 1994). Especially in the case of novel situations, the relationship between the knowledge required for the solution of a problem is often not very clear –for the novice unlike for the expert. Schon (1979) argued that in order for an individual to understand a situation, the process of problem finding is as central and important as the process of finding the solution of the problem and creating the appropriate connections between the problem and the solutions. Therefore, in terms of the use of analogies, it is plausible to assume that another important factor for the failure in promoting conceptual understanding is that teachers or researchers who create a problem are more likely to see the similarities between the base and the target. Moreover, ready-made analogies do neither reflect, nor are being based on students' prior knowledge but rather on teachers' or researchers' conceptual understanding and this is why the former could not interpret and use the analogies as the latter would like them to do so (Duit et al., 2001). The way that students create and use their own analogies could show how they map relations between the base and the target as well as their conceptual understanding upon which they generate their analogies, however as Atkins (2004) commented, this theme is not well studied.

Wong (1993b), echoing Schon (1979), stated that students' prior knowledge plays an important role in the perception and interpretation of a new situation in comparison to situations in which students have ready-made explanations. Due to the nebulous nature of the situations that differ from those of traditional instructional contexts, children need to identify and represent the scientific phenomenon in such a way that it could help them to obtain a better understanding. Thus, one avenue of future research would be to examine the spontaneous and unpredictable use of analogies in novel situations rather than investigating the analogies used in situations that are familiar.

According to Wong (1993a,b), even in terms of learning science, it is perhaps more valuable to understand how children can productively generate their own analogies to advance their conceptual understanding of scientific phenomena rather than to examine how students use ready-made analogies in an attempt to conceptualise a new situation. Brown (1993) concluded that analogies have the potentiality to help children construct a new explanatory model for an unknown situation.

Considering reasoning by analogies as a central aspect of human cognition, responsible for the generation of ideas and the growth of human knowledge (Duit, 1991), analogical reasoning should be seen as a resource for the understanding of science (Leech, Mareschal & Cooper, 2008). Science education should investigate further the way that students generate their own analogies in order to provide the appropriate guidance to the students for an effective use of self-generated analogies. Therefore, it could be more productive to investigate how students generate their analogies rather than to explore how they use analogies generated by a researcher or a teacher and then interpreted by the student.

There is, however, a small number of studies which have attempted to investigate the success of having students construct and develop their own analogies in ways that appear to engender understanding of science concepts that seem to be difficult (e.g., Sandifer, 2003; Cheng & Brown, 2010). What is missing in the literature is the answer to why these self-generated analogies frequently lead to erroneous predictions; secondly a gap exists in terms of what conceptual resources are used in these analogies and what the connection with the erroneous predictions is. In other words, why the self-generated analogies can lead students to reason erroneously and if there is some basic knowledge (like diSessa's p-prims) that students use to build their analogies on. The following section provides a review of the research about students generating and using their own analogies.

2.7 Spontaneous and self-generated analogies

As it was discussed in the previous section very few studies have been conducted about students developing their own analogies to understand and learn science (Sandifer, 2003). Nevertheless, there has been some research into how students constructed and developed their own analogies. What follows is a definition and explanation of spontaneous analogies and a review of the studies that dealt with this type of analogies.

Clement (1987) investigated the way that problem solvers think when they confront a new situation, through a process described as thinking aloud. The aim was to study the act of considering an analogous case which was not given by the researcher. This is nearly what a spontaneous analogy is. Podolefsky and Finkelstein (2006) defined a spontaneous analogy as being one generated without any provocation. In agreement, Clement (1987) describes spontaneous as having the meaning of self-initiated in contrast to other situations where students are presented with an analogy or part of it and are expected to complete or use it to explain and understand a phenomenon or a concept. In this sense, a spontaneous analogy is similar to a self-generated analogy as the latter has the meaning of an analogy that is created by the individual as opposed to analogies that are provided and expected to be applied. The subtle difference being that, whilst a self-generated analogy could be prompted, a spontaneous analogy should be self-initiated.

Spontaneous use of analogy takes place when the individual spontaneously shifts attention to a different situation from the original one because it is believed that there are similarities between the problem presented and the analogous situation. The precise definition might be deduced from the criteria needed to recognize the occurrence of a spontaneous analogy.

According to Clement (2009), in order for a spontaneous analogy to be identified, the generation of situations that share similarities with the original problem but on the other hand they do differ should be observed. These criteria are however, very similar to the characteristics of analogies as they have been described in previous sections of this present study. Nevertheless, the difference is that spontaneous analogies do not necessarily give an answer to the original problem. Moreover, spontaneous analogies rule out valueless cases that do not share functional or structural similarities and are restricted to surface similarities. Another criterion that defines the spontaneous generation of analogies is its separation from other problem-solving processes such as breaking the problem in smaller parts, analysing it in terms of principles and produce extreme cases (Clement, 1988).

The criteria discussed in the previous paragraphs could be used to define what a spontaneous analogy is and how it differs from analogies that are used under the instruction of researchers or teachers. A question that reasonably arises is what are the processes for productively using a spontaneous analogy and what are the methods for generating spontaneous analogies?

In their first experiment, Gentner and Gentner (1983) made the assumption that high school students would reason by analogy on their own. In order to get a more detailed view of how these analogies are generated, Clement (1988) investigated the use of spontaneous analogies by experts. The observations of this experiment led to the conclusion that there are four processes in making productive use of a spontaneous analogy. These processes are consistent with the four basic stages suggested (Clement, 1982) for the construction of an analogy. These four processes are:

1. Generating the analogy. A base analogous to the target is constructed. Between the target and the base, a provisional relation should be set up.
2. Establishing confidence in the analogy relationship. The cogency of the analogy is confirmed through critical examination of the relation between the base and the target.
3. Understanding the analogous case. Examination and analysis of the base. Applying findings to target.
4. Inferences are drawn from the base to the target.

In agreement with these stages of constructing an analogy Gentner (1977) proposed the generation of spontaneous analogies to be broken down into five sub-processes: a) accessing the base situation, b) producing the mapping between target and base, c) evaluating the match between target and base, d) storing inferred conclusion in the target situation, e) extracting the commonalities between the two situations. Sub-processes b and c are those that uniquely define analogies (Gentner, 1989) and these stages are similar to those proposed by Clement (1982).

Clement (1988) also identified three methods (listed below) for producing spontaneous analogies. It should be added that Clement observed the first method fewer times in comparison to the other two with the second being the one observed most frequently.

1. Generation based upon a formal principle. For example, a formal abstract principle or a single equation which can be applied in two or more different contexts (e.g., conservation of charge or energy).

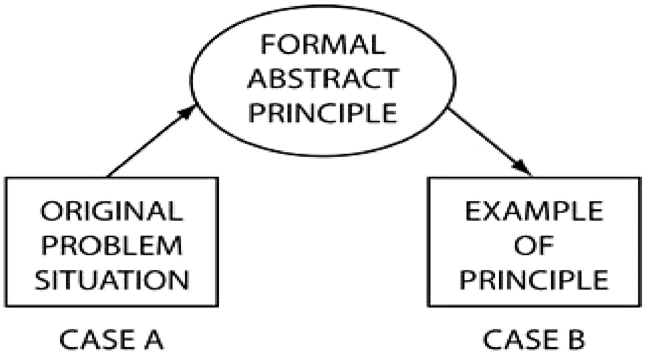


Figure 2.2 Schematisation of method 1, generation via formal principle
Source: Clement (1988), page 574.

2. Generation via a Transformation. In contrast to the previous method, in this case there is no mention of an equation or a formal principle. Student creates an analogous case B by changing some features of the original case A (modification of the original situation).

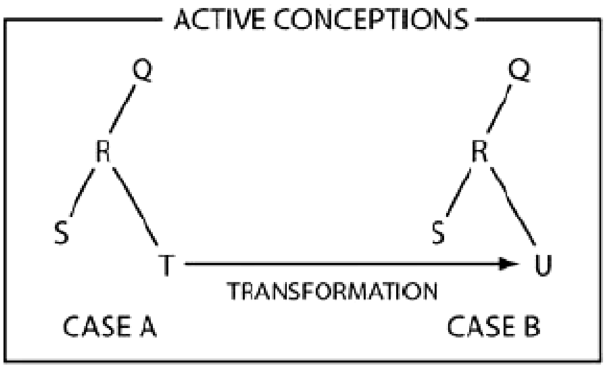


Figure 2.3 Schematisation of method 2, generation via a transformation.
Source: Clement (1988), page 574.

3. Generation through an association. Rather than generating an analogy via a transformation, student is reminded of an analogous situation B in memory. As Clement commented, the analogous

case may differ in many aspects from the original situation but it can still have many and important similar features.

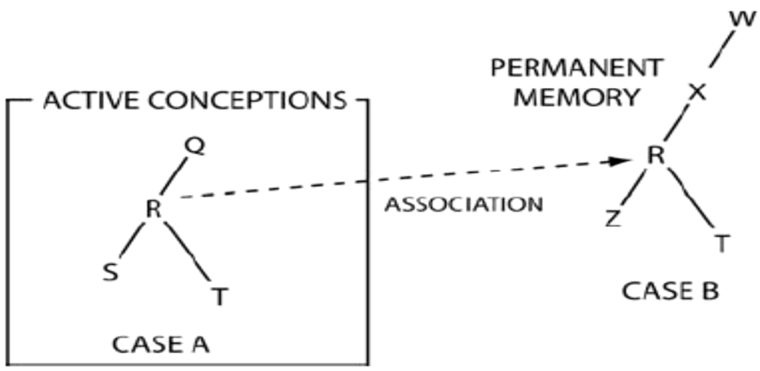


Figure 2.4 Schematisation of method 3, generation via an association.
Source: Clement (1988), page 574.

The above categorisation has many features in common with the distinction that Gentner (1983) made between abstraction, analogy and literal similarity discussed elsewhere in this review.

Although Clement's methods and processes for generating and effectively using a spontaneous analogy are drawn from experts they could be applied to students' reasoning as well. That is not to say that experts and students always categorize problems and reason the same way as argued by Chi, Feltovich and Glaser (1981). Thus, it could neither be assumed that the students of the present study would follow the processes that Clement suggested, nor could it have been predicted which method of generating spontaneous analogies would be the most preferable to them. The present study is founded upon the abovementioned processes of spontaneous analogical reasoning. This framework is used here to categorise the analogies that students might generate (details about how this framework is used are provided in the methodology chapter).

Again, regardless the process of constructing an analogy, it should be reminded that the basic principle for generating them is that the target and the base need to be similar to some extent. For instance, they can be similar concerning a mapping of characteristics, like flowing water is like electricity, or they might be similar in terms of the mapping of associations like the relationship between the solar system and the hydrogen atom described previously.

Moreover, any failure to generate and use a spontaneous analogy effectively might not be attributed to lack of knowledge of the particular situation presented to the students, but rather to the inability or failure on the part of the students to make inferences from the base to the target (Clement's fourth stage), or their failure in mapping the similarities (process proposed by Gick & Holyoak, 1983, discussed in previous section). Nevertheless, the investigation of the reasons that could possibly lead students to use an analogy ineffectively exceeds the purpose of this study.

2.8 Research on spontaneous and self-generated analogies

The previous subsections offered an overview of the structure of analogies and other comparisons in general, as well as the function of the latter in reasoning processes. The present subsection reviews empirical studies on children's ability to perform analogical reasoning.

An influential work on reasoning and self-generation of analogies in novel situations is the early work carried out with advanced school and undergraduate students (students aged between 17-21 years) by Viennot (e.g, Viennot, 1979) and Villani and Pacca (1990). According to Saltiel and Malgrange, (1980) the assumption of an organised way of thinking and reasoning could help in the consideration of the mistaken ideas that students hold in science.

Another early study dealing with the issue of students generating their own analogies was that of Gentner and Gentner (1983). In their first study they administered a multiple choice test on parallel and series electric circuits to high school and college students (46 students). In this test, they asked students to elaborate on how they perceived electricity, and used answers to investigate whether a moving object analogy or a water analogy was expressed in students' explanations. The primary aim of this study was neither to examine the analogies that students generated, nor to explore the way of generating them. Gentner and Gentner assumed that students would generate analogies on their own and used the analogies expressed in order to determine which analogy (the water analogy or the moving crowd one) would be more appropriate to be used when teaching about electricity.

As mentioned above, Clement (1988) investigated the way that expert problem solvers generate spontaneous analogies in order to obtain a more detailed view of this process. Thus, the study concentrated on identifying the spontaneous analogies in experts' reasoning and on describing how analogies were generated.

In the research, ten advanced graduate students and professors in technical fields were shown two springs with equal masses attached (coiled spring problem) as shown in the following figure (figure 2.5). They were asked which of the two springs would have a longer stretch.

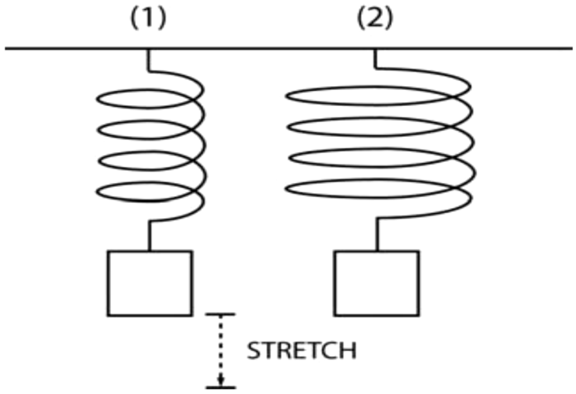


Figure 2.5 The two springs' problem Source: Clement (1988), page 565.

The majority of the students (7 out of 10) generated spontaneous analogies while reasoning about this situation. The experts used these analogies effectively in order to explain their thinking and solve the problem presented to them. The most common way of generating an analogy was through modification of the original problem. Although Clement did not report upon this issue, from the analogies provided as examples it could be assumed that students created an analogous case focusing upon things they observed in their daily life or situations that were more familiar with. Gordon (1968) would have agreed with this assumption and has pointed out that the role of spontaneous analogies is to connect familiar experiences and knowledge with unfamiliar situations and ideas. These can also act as a cognitive tool for generating new explanations. A typical example of the analogies found in Clement's (1988) research is the use of a bending diving board that helped some of the experts to approach and finally solve the problem (a longer diving board bends more, therefore a longer spring stretches more as well). The findings concerning the presence of spontaneous analogies and the processes of analogy generation have previously been discussed in the present chapter.

Continuing, Wong (1993b) investigated the spontaneous analogies that eleven undergraduates of the school of education generated in an attempt to conceptualise and describe the way that a piston/cylinder (syringe) device works. This study differs to these mentioned above but again the purpose was not to investigate the analogy itself and identify any similarities in students' analogical reasoning, but rather to explore students' analogical reasoning as it evolved in the absence of any prior knowledge about the scientific phenomenon presented. The students in this study created, modified and evaluated the spontaneous analogies they generated for a variety of reasons.

As Wong (1993b) found, students used analogies for three basic reasons: a) to familiarise with the new and unknown situation, and to impel students to b) construct a representation of the new problem by using pre-existing knowledge and c) to form the basis for them to generate new questions and problems redefining the phenomenon along these lines. The results of that study showed that spontaneous analogies motivated students to draw conclusions and stimulated their comprehension of the problem. Also, analogies helped them to explain and advance their understanding of the new phenomenon through the evaluation and refinement of their self-generated analogies.

In another study, Pittman (1999) examined the analogies that eighth grade students generated. The aim of the research was to assess whether student-generated analogies had the potentiality to reveal students' understanding about protein synthesis. The eighth grade students that participated in the study were firstly taught the topic of protein synthesis and then, were instructed how to generate their own analogies. Students were also taught how to understand and use teacher generated analogies, then worked in groups so as to create and apply their analogies. Following the end of the unit, after receiving feedback and discussing their analogies, students were interviewed by the researcher.

Although ways of generating the analogies and any similarities between them were not explored, the findings of the study support the view that students' analogies are more valuable as opposed to teachers' and experimenters' provided analogies. Pittman (1999) reported that students' self-generated analogies had a more important effect and were of greater interest to them. Along this line, students stated that sometimes they could not understand the analogies provided by the teachers and that in some cases these analogies had a negative impact in understanding and explaining the new situation leaving them (in some cases) confused. Pittman comments that students' self-generated analogies might serve as a diagnostic form of assessment thus revealing any misconceptions that might be perceived.

Cosgrove (1995) conducted a research to investigate analogies generated by high school students. To explore the use of analogies and self-generated explanation models Cosgrove asked physics students to consider problems about electric circuits. A teaching strategy was developed which gave students the opportunity to generate analogies on their own and then modify them according to comments and feedback they received. The findings suggested that the use of self-generated analogies increases students' confidence to work out problems on their own, feeling more capable to reach a conclusion and exhibited the ability of "mature and sustained thinking" (Cosgrove, 1995, p.307). Lastly, the study shows that self-generated analogies provide students with an appropriate framework within which they can explain and reason about phenomena.

Sandifer (2003) explored the analogies that junior and senior physics college students generated and how these could help them in understanding the notion of force and energy. According to the findings, analogies not only help students improve their understanding of the new situation, but the generation of a spontaneous analogies can also facilitate the deeper understanding of knowledge already acquired. In agreement with the findings of the research, Pittman (1999) studying biology concepts, concluded that children who create and develop their own analogies show a "deeper understanding" (p.16) of the science topic studied.

Additionally, in Sandifer's (2003) study the generation of analogies by several students triggered others to act similarly, since data was collected in group discussions suggesting that group activities can be a more productive way of researching students' reasoning by the use of analogies. As Sandifer notes, group interactions can help students to generate their own analogies.

Finally, the data of the latter study showed that it was easier for students to generate analogies regarding qualitative problems. This might be because in qualitative analogical reasoning the relationship between the known and the novel situation needs not to be exact in order to facilitate students' reasoning and understanding of the novel situation. Another reason could be that human beings observe the surrounding world, to find out what is happening and then attempt to affect it while using fewer and less precise data than these necessary to think quantitatively (Forbus, 1996). An assumption which could be made here is that, from an evolutionary perspective, humans have evolved to think qualitatively which might help explain why people find learning, applying mathematics and thinking mathematically difficult (De Lange, 1996).

In the case of the generation of quantitative analogies the problem lies in the difficulty to use the mathematical solution to the two different problems whereas the analogies used might not have any similarities (concerning the physical concepts/phenomena concealed in the analogy). It therefore would be more advantageous to examine students' capability of generating analogies in qualitative problems rather than in quantitative ones.

Spicer-Dance, Mayer-Smith, Dance and Khan (2005) explored the role of students' analogies in order to promote conceptual understanding of the oxidising power of halogens. Undergraduate students of chemistry used self-generated analogies in their explanations and improved their understanding. More importantly, it was found that students who created and developed their own analogies were able to accomplish a better achievement and conceptualisation of notions in comparison to students who were provided with analogies by their instructors.

In a more recent study, Cheng and Brown (2010) explore the explanatory models that children spontaneously used when explaining magnetic phenomena. The researchers used a framework developed by Brown himself (1993, 1995) which offered an alternative to Vosniadou and diSessa's perspectives as to narrow the gap between them. The framework Brown proposed for the representation of student's thinking is broader than those suggested by diSessa and Vosniadou mentioned earlier in this study.

The elements of the framework are: a) core intuition (knowledge drawn from daily experiences), b) implicit conceptions (deduced from generalized tacit assumptions from everyday experiences), c) conscious conceptions (causal intuitions related with the core intuition and implicit conceptions), and d) verbal symbolic knowledge (consciously remembered principles, like laws and equations). Brown (2010) stated that these elements facilitate the analysis of students' conceptions focusing on two features of their notions. On the one hand they enable focus on the consistency and coherency of students' notions and on the other hand on conceptual and subconceptual aspects of student's thinking.

Using this framework and six case studies (equal proportion of third and sixth graders) Cheng and Brown (2010) found that it was easier for students who employed knowledge deriving from every day experience to construct explanatory models. However, the explanatory models that students provided were provisional and in each situation students used different explanations despite the situation presented being the same (Cheng and Brown investigated magnetism phenomena in their study). It might be argued that these students had different misconceptions for each situation presented to them. Alternatively, it could be assumed that these students used the same idea differently according to context or that they used an entirely different notion to explain the phenomenon.

Although Cheng and Brown's study investigated the conceptual resources that students use to explain something they have never considered before, more attention was paid to the way students used these resources (construction, critique and revision of a model/explanation) rather than to the resources themselves. Also, the modelling language that Brown suggested seems to focus more on the categorisation of students' ideas rather than the nature of students' conceptions.

2.9 The present research

There has been no previous research regarding the way students reason when been confronted with a novel situation and in particular whether the way that they reason about identical novel situations changes with age.

It therefore seems a productive line of research to consider whether, and if so, how students reason about a novel situation with special attention on how students of different age reason about the same novel situation. A comparison between spontaneous responses and misconceptions -about the same situation- found in literature could shed some light on the issue if a misconception is a stored conceptual framework or results from an act of construction. Similar misconceptions about the same phenomenon could therefore be understood as deriving from a common way of reasoning and the application of the same p-prims and/or the use of the same analogies.

The present study focuses on the use of analogies developed by students during their predictions of novel situations and what conceptual resources they employ in their analogies.

Chapter 3

Methodology

3.1 Introduction

This research is an exploration of students' spontaneous and self-generated analogies as they attempt to make predictions of novel situations. Mixed methods are employed for the needs of the present study. The strategy employed to fulfil the aim of this research comprises interviews and questionnaire administration.

It should be added here that the term students in the previous paragraph is used interchangeably with the term participant throughout the present chapter in order to describe not only the study sample of this research but the subjects of studies reviewed in the following sections as well. However, in some of the studies reviewed the term participant was used to reflect the study sample including students and others. An example is the research carried out by Clement (1988) with participants being solely scientists in technical fields.

3.2 Background

There are two main approaches for carrying out investigations about students' ideas and predictions of phenomena. These are qualitative or quantitative research with a long debate being reputable about the relative value of quantitative and qualitative inquiry (Patton, 1990). Both approaches have emerged from different research needs and have been used to support different theories about student's views in different domains of science education research.

There is an on-going debate about the approaches that have been employed in the research of students' ideas, predictions and explanations in science. Disagreement has basically arisen from the inconsistency of the results produced by different research approaches. What seems to be the case is that this inconsistency is more connected with the way of analysing and interpreting students' ideas rather with the ideas themselves. Not to mention that, in most cases the critics of a theory about students' ideas (e.g., if students' knowledge is theory-like rather than consisting of many quasi-independent elements) chose an alternative approach than the one that researchers supporting the different perspective had adopted. In other words, different needs have triggered the need for different approaches, and research stimulated changes not only in theory but in means of analysis as well.

In recent years education research has moved away from essentially employing quantitative methodologies to extending greater emphasis to the use of qualitative approaches. Studying three respected science education journals, International Journal of Science Education (IJSE), Journal of Research in Science Teaching (JRST) and Science Education (SE), Devatak Glazar and Vogrinc (2010) conclude that qualitative research approaches are preferred over other methods when exploring students' understanding of concepts and phenomena. However, there is an opposite tendency in some topics such as research in the area of student's ideas about basic astronomy concepts.

Also, this area of students' astronomical ideas constitutes a typical example of the debate mentioned above. Several authors argue that students' understanding of the Earth and its motions show some consistency (e.g., Vosniadou & Brewer, 1994; Vosniadou, Skopeliti, Ikospentaki, 2004), whereas other researchers have not found such internally consistent models among their interviewees (e.g., Schoultz, Säljö & Wyndhamn., 2001).

The aforementioned inconsistency of findings is suggestive of a relationship between the research questions and the results being produced. Moreover, as Panagiotaki (2003) indicated, different testing methods of student's conceptions and understandings evoke different responses.

Studies on the use of spontaneous analogies generated by students have followed the general tendency mentioned above. In most of these studies, qualitative approaches were chosen. There is a typical design being followed in these studies: individual participants or an experimental group, are familiarized with a problem (described in the previous chapter as the base) and a solution. Continuing, participants are asked to approach a different problem that shares some relations to the first one and solve it using the first case as an analogous situation. Afterwards, researchers analyse if trained participants used analogies in the process of problem solving more often than those who were not trained. Also, they examined whether this approach using analogical problem solving could help participants to achieve a better conceptual understanding of both the base and the target.

Studies on problem solving via analogical reasoning involve analogies that are provided by the researcher rather than the student (e.g., Gentner & Gentner, 1983; Summers, Kruger & Mant, 1998). This approach faces a basic disadvantage as Pauen and Wilkening (1997) pointed out. The problem appertains to the representation of the base and the target given to the students. Students' representations of both the target and base could possibly be different from that of adults. This way, the young participant might not be able to perceive the proposed analogy as a tool that can facilitate the solution of the problem. But this is not the only limitation of such an approach.

More importantly, in most of these studies using the aforementioned approach, spontaneous use of analogies was hardly achieved by participants and identified by the researcher. Spontaneous transfer of information between the base and the target without any explicit indication from the researcher or the teacher on how and when to use the analogy was surprisingly low (Brown, Kane & Long, 1989). Even though participants in these studies did perform better in terms of using analogies in their explanations and achieving a better understanding of the concepts involved, spontaneous use of analogies still seems to be the exception rather the rule (Brown et al., 1989). As Pauen and Wilkening (1997) suggested this might be due to the different ways that participants consider the proposed analogy to those of the experimenter who generated it. In other words, participants are trying to apply the ready-made analogy without attempting to generate their own ones to approach and explain a problem. This leads to low spontaneous transfer rates, albeit participants might have well-developed abilities to reason by using analogies.

Additionally, children's naïve theories about physical phenomena differ substantially from those of adults and experts (Carey, 1991). Thus, spontaneous transfer rates should be tested by using analogies that involve causal structures that are familiar to the students participating in a study instead of analogies that make sense to the person who generates and then provides them to the participants (Goswami & Brown, 1989). On the other hand, it could be better to give students the opportunity to generate their own analogies. This might have two implications though. Paune and Wilkening (1997) suggested that this implies intensive pretesting so as to ensure that the causal relations involved in the analogy are understood by the participants and that, moreover, the analogy is perceived in the same way both by children and adults.

On the contrary, if students are being given the opportunity to construct their own analogies they will seek for causal and similarity relations on their own. As Pittman (1999) noted, these similarity relations might be based upon students' observations and their prior knowledge of the base (the original problem presented to them).

The needs of the present study suggest that such a design would not serve its purposes. The methodological problems being previously discussed can be avoided by investigating the analogies that students generate on their own in natural settings in contrast to analogies provided to students in instructional materials or in teachers' spontaneous generation (Dagher, 1995). This approach has the basic advantage of referring to examples chosen by students and therefore it can potentially reveal how these analogies can be used for predictions of novel situations and furthermore what constitutes the basis for generating them.

What follows is the description of the focus of this present study and subsequently an analysis of the way that the research approach has been chosen so as to serve the purposes and to meet the needs of the study.

3.3 The research focus

The present study aims to provide an exploration of students' predictions in novel problems they have not considered before. Researching about students' explanations and predictions in novel situations could reveal students' prior knowledge. This prior knowledge could be related to what is named as misconceptions in the literature, or the source that generate them (Rowlands et al., 2005). As it is already being mentioned in the previous section, it might be more plausible to consider those that are created when students face a situation.

The purpose is to investigate the way students make predictions about novel situations. These situations will be novel in the sense that students will not have seen them before and, therefore, will not have a pre-existing answer for them. Their predictions will be analysed to ascertain whether they can be viewed and understood as being a way of explaining on the basis of analogies. In addition, the explanations of different aged students will be compared with regard to the way they reasoned and explained the novel situation presented to them as well as to the conceptual resources they used. In other worlds, it will be investigated whether the analogies involved are related to the activation of more basic knowledge elements, like p-prims. However, the basic aim is to see if students of different ages draw on the same analogy (or analogies) when faced with the same novel situation.

The basic research questions guiding the present study are:

a) How do students of different ages answer questions about novel situations?
b) What analogies do they use in their predictions?
c) To what extent do students of different ages draw upon similar analogies?
d) Is there any evidence of basic mental constructs, i.e. p-prims, in the analogies students generate when they make predictions about novel situations?

Students' ideas about some concepts of physics (located within six novel situations) will be examined. The study will investigate the alternative conceptualizations of students from different age groups in an attempt to identify any commonalities in their views as well as the way they reason in novel situations (students should not have any prior experience of the specific situation they are presented with). Whilst they might have some knowledge of the underlying concepts involved in the novel situations (through formal or informal instruction) the basic methodological approach is to present situations that are novel in their structure that is reasonable to assume that the student will not have previously encountered them. Nevertheless, if a situation arises in which it is found that students have been taught using examples that are highly similar –to the extent that the examples presented in the study might not appear novel- then the focus in that specific (unexpected) case will be on how they apply their prior knowledge.

3.4 The methodology

Generally speaking, the word method concerns those techniques of eliciting answers to predetermined questions, measuring or recording information, describing a phenomenon and carrying out experiments (Cohen, Manion & Morrison, 2007). As Kaplan (1973) suggested the purpose of methodology is not to understand the findings and the products of a research, but to perceive the way of enquiring.

The present section will examine the methods and the type of questioning used in order to investigate students' predictions and answers in novel situations. In the following sections of this chapter, the term methodology will be referring to the approaches used to collect data, not for the data analysis. Details about the methodology used for the data analysis will be presented later in section 3.8 of the present chapter.

The strategy used to collect the data and the construction of instruments used, are presented in the following subsections. There were two data collection phases (a pre-pilot and a pilot study) conducted before the main data collection phase. From the pre-pilot and pilot study, there were some interesting issues that emerged which led to the refinement of the initial strategy. These two phases, the issues and the modifications which derived from them are discussed further in section 3.7 of the present chapter.

3.4.1 A cross-age study

This research is a cross-age study involving students from primary and secondary education (details for the selection of the age groups are given below in section 3.9). As Cohen et al. (2007) argued, this type of study can offer a "snapshot of a population at a particular point in time" (p. 213). In this sense a representative sample of students in secondary and primary education could be examined producing indirect measurements of their intellectual development. In other words, drawing students from representative age levels at a particular point in time would bear some features of a longitudinal study in the sense that development over the different age levels could be identified. Therefore, any changes in the way students make use of analogies in order to make predictions of novel situations as well as the analogies themselves could be studied by conducting a cross age study.

Moreover, as Abraham, Williamson and Westbrook (1994) suggested, studies with children from different age groups as participants are considered to be productive by giving insight to the role that the ability to explain phenomena and exposure to formal instruction plays in the students' development of concepts about science topics. In agreement with this statement, Yilmaz and Alp (2006) pointed out that cross-age surveys have the potential to reveal shifts in concept development that takes place as students mature in terms of their intellectual development and how this development is affected by the reception of additional formal or informal instruction.

One of the purposes of the study is the investigation of students' ideas, whether these are persistent across different age groups as much as to what extent these ideas could be alternatively viewed as a way of predicting and reasoning on the basis of analogies. Therefore, this aim of the study led towards a comparison of the explanations students of different age gave and whether they used similar analogies. To achieve the latter it was determined appropriate to employ a cross-age survey.

3.4.2 Study sample

Sampling decisions were made in the early design stages of this research as they were informed by the principal aims of the study. The participants were chosen with the purpose of giving a detailed account of the way that students make predictions about novel situations while ensuring that all relevant age groups are included, providing the ability for the researcher to explore any differences in perspective among the age groups.

An important issue related to sampling decisions in cross age surveys relates to the complexity of data handling and sampling in cross-sectional studies. Rose and Sullivan (1993) have noted that if participants belong to different groups, there is a possibility that their responses might not be comparable. In agreement with that, Lietz and Keeves (1997) pointed out that cross-age studies require close attention to sampling in order to ensure that the sample serves the purposes of the study and the information being based on is comprehensive and representative (details about the selection of the study sample are given in the following section).

However, in sharp contrast, Cohen et al. (2007) argued, that cross-age studies enable groups to be compared and this approach is preferable for cases such as the present study in which the cost and the time needed for undertaking the research needs to be taken into consideration as well. Rose's and

Sullivan's aforementioned claim could be interpreted as an intention stressing the importance of a careful design and selection of the study sample in cross age studies.

With accessibility being a key issue as well as a factor that must be early decided in every social research as Punch, Harden, Marsh and Keating (2013) argued, one of the primary aims, in terms of sampling design, was to ensure that access is not only permitted but is practicable as well. The influence of accessibility on the decision about the subset of the total population to be recruited and the place for conducting the research was of crucial importance. The researcher of this present study had previous experience in following the processes required for granting the permission from the Greek Ministry of Education.

The above issues led to the decision to carry out the research in Greece rather than in the UK, for example, where there was not any experience in requesting the permission to access schools. In addition, on behalf of the researcher, there is a desire to work in Greece in the future which reinforced the decision to carry out the survey there. Nevertheless, it could be argued that there would not be major differences even if the research was to be conducted in the UK or in another country, for, as Driver et al. (1994) have argued, children's ideas and views in science do not seem to be heavily culturally dependent.

3.4.3 Size of the study sample

Generally speaking, large study samples ensure greater reliability and also enable more sophisticated data analysis to be employed (Cohen et al., 2007). However, factors like expenses, time and the previously discussed issue of accessibility would make the examination of the whole population or even a large study sample unfeasible. These led to the decision to gain information from a subset of the total population of students in Greece with attention being paid as to ensure that the sample used was representative of the total population from which it was drawn. By choosing the size of the study sample in this particular way it was hoped to achieve a high degree of population validity. The latter is a concept that refers to the extent to which it is possible to make generalisations from the study outcomes, obtained by collecting data from a relatively small sample, to members of a much larger population (Bracht & Glass, 1968; Cohen & Manion, 1982). High levels of population validity can enhance the accuracy of a study. What follows is an estimation of the total Greek population on the basis of which the decision of the study sample size was made in order to be considered representative.

Education in Greece is compulsory for children aged from 6 to 15 years. Compulsory education includes primary, which is called Demoticon (Δημοτικό), and secondary lower education known as Gymnasium (Γυμνάσιο) in Greek. Mandatory attendance at primary education lasts for six years whereas lower secondary education lasts three. Post compulsory secondary education is divided into two different school types. Students aged from 15-18 years have the option to continue their studies in the first school type, which is the unified upper secondary school (named as Unified Lyceum, Ενιαίο Λύκειο) or the technical vocational educational schools (known as Technical Lyceum, Τεχνικό Λύκειο). The duration of studies in both schools is three years but there is an option for students in the technical vocational schools to study for two years awarding a lower school leaving certificate (A level) than those who study for three years (B level).

The decision about the size of the study sample was made by starting from the total population and working down to a smaller and representative group. Therefore, the total population was necessarily identified in order to assess the representativeness of the sample. The table below presents an estimation of the total population of students in Greece. The data presented here were gathered in the academic year 2008-2009 from the directorate of statistical and organization studies of the central agency of the Greek ministry of education and religious affairs (The Education, Audiovisual and Culture Executive Agency, 2009/2010)

	Number of students	***Average infant class size***
Primary education	*640,036*	*18.6*
Compulsory secondary education	*345,755*	*23.0*
Unified upper secondary school	*244,644*	*21.0*
Technical vocational educational school	*86,123*	*15.0*
	Sum = 1,316,558	*Weighted average=19.97 (≈20 students)*

Table 3.1 Total population of Greek students

Source: The Education, Audiovisual and Culture Executive Agency (2009/2010).

The decision about the number of the students that were needed so as to ensure that the sample would be representative of the target population was made by using a sample size calculator. The calculation was made by using a free web site (Creative research systems, n.d.). In order for the calculation to be made there were two factors used, the confidence interval (margin of error) and confidence level. The latter is a sign/measure of certainty. It represents how often the true percentage of the total population who would choose an answer lies within a given variation level which is actually, the confidence interval. Both factors are expressed in percentages.

For instance, consider a sample of 1000 students in a country being asked about which subject is their favourite with 650 (65%) of them saying physics. With a confidence interval of 6%, the researcher would have a high degree of confidence-this value of this degree depends on the level of confidence-that if the question was asked in 1,000,000 students (the entire population in this country), between 590,000 (59%) and 710,000 (71%) would have said that they prefer physics. In this case a choice of 95% confidence level ensures that the true percentage of the entire population that would answer they prefer physics subject is between 59% and 71%, with a certainty of 95%. In other words if the same question was to be asked 100 times with different study samples of 1000 students, there is a probability for the researcher of recording the same preference of physics (590-710 students) 95 out of the 100 times.

Overall, the larger the confidence interval it is, the more confident the researcher can be that the total population responses would be within that range. Moreover, the higher the confidence level the researcher is attempting to reach, the greater the sample becomes (Cohen et al., 2007).

For the needs of the present study, a 95% confidence level was chosen as appropriate because, as Cohen et al. (2007) suggest, this is the value of confidence level usually used by researchers and this was to be used in conjunction with a confidence interval of 7%. Entering these values and the total population of Greek students, the calculation showed that a sample of 196 students was needed to be interviewed in order to achieve a 95% confidence level for the target population. Accepting that the average size of the typical size of Greek class is approximately 20 students, it was decided to recruit ten different classes. The following section presents the selection of participating students' age range.

3.4.4 Students' age range

As mentioned above, this research is a cross-age study involving Greek students of primary and secondary education. Table 3.2 below presents the group ages of students recruited:

Primary education						Secondary education						
Year	*1*	*2*	*3*	***4***	*5*	***6***	*7*	*8*	***9***	*10*	***11***	*12*
Ages	*6-7*	*7-8*	*8-9*	*9-10*	*10-11*	*11-12*	*12-13*	*13-14*	*14-15*	*15-16*	*16-17*	*17-18*
	Compulsory education											

Table 3.2 The group ages of students recruited.

It should be noted here that from Year 1 to 4 students' of primary education are not being taught any physics or chemistry. The first subject of physics is introduced in Year 5. Thus, the first age groups are Year 4 and year 6 in order to investigate if there is any impact of formal instruction in the way that students reason about the novel situations. It was decided to start from Year 4 rather than earlier, because several researchers (e.g., Piaget, Montangero & Billeter, 1977; Gallagher & Wright, 1979) have claimed that students younger than 10 years of age lack the fundamental cognitive abilities to reason using analogies.

However, more recent studies have shown that six-years old students (Inagaki & Hatano, 1987; 1991) or even four-year olds (Carey, 1985) have the capability of using analogies in their explanations, but in these experiments the base was chosen and provided by the researchers and the students had to make the transfer to the new situation (target). The difference in the present study is that analogies were not provided by the researcher to the students as the aim was to investigate whether students make their predictions on the basis of self-generated analogies.

Nevertheless, there was a pre-pilot study conducted in an outside-classroom setting with four students aged between 6-9 years in order to see whether the questions were meaningful for students younger than ten years old and whether these students were able to make predictions and furthermore, explain their thinking. Results from this pre-pilot phase showed that students at this age lacked the ability of predicting and reasoning about the situations designed for the present study and thus, they did not constitute an age group of the study sample.

In the first year of compulsory secondary education, students are not taught any physics and chemistry with these subjects being introduced in Year 8. It was therefore decided to study Years 7 and 9 to see if there is any difference in the way that students reason about the novel situations after having received instruction in these two subjects. Although there are two compulsory subjects, one in physics and one in chemistry, in the last three years of secondary education in the unified upper secondary school (Year 10 to 12), students (Year 11) have to choose a domain of focusing their studies. One option is natural sciences (physics, chemistry, biology) and the other is philosophy, Latin and Greek literature. Therefore, the other age group chosen is that of the Year 11 in order to see if there is a difference between students that study more physics and chemistry in comparison to those who do not at all.

3.4.5 School selection

As described above, the decision was to study a sample of Greek students striving for representativeness on the level of the total population of students in this country. The geographical distribution of the schools selected was not random because the process for selecting which schools would take part in the study was determined by taking into consideration the process required for granting the permission for conducting the research from the Greek Ministry of Education. Permission would be given only for those schools that the researcher namely asked to access. However, in the case that any of the selected schools, after permission would have been granted by the Ministry of Education, were unwilling to participate (either due to the head-teachers' or teachers' decision), it would have made it difficult, if not impossible, to recruit another replacement school. This is because, in this case, the researcher would have to repeat the process of permission asking without, however, being definite that the stakeholders of this reserve school would provide the access. Also, the decision of the Ministry of Education to provide access is usually issued two-three months after the submission of the related application. Thus, any repetition of the whole process would be too time-consuming.

As such, the basis for the school selection was first of all a practical one. It was decided to recruit some of the schools in which there was a pre-existing professional relationship between the researcher and the stakeholders in order to ensure that after being granted permission by the Ministry of Education, they would not deny participation in the study. Such a professional relationship existed between the researcher and some teachers, head-teachers and science education state school advisors in the area of central Greece where it was decided to conduct the research.

Moreover, according to the Hellenic Statistical Authority (2012/2013), more than one third of the total Greek population of students enrolled either in primary or secondary education study in schools located in central Greece. It was therefore felt that and conducting the research in this particular area was believed to be providing the opportunity to access more schools in a relatively small geographic area (in comparison with the total geographic space of Greece) reducing at the same the total data-collection period and travel expenses.

An initial contact via e-mail and letter was made directly with the head-teachers of each school. The letter briefly outlined the research and offered details about what was required. At the end of the letter it was suggested to contact the researcher by telephone to let indicate if they were interested in taking part in the project. Twenty two head-teachers were contacted until 10 of them (4 of primary and 6 of secondary education) gave their consent to conduct the research in their schools. After this first contact, the researcher prepared all the appropriate documents in order to obtain permission from the Greek Ministry of Education about these 10 particular schools. After permission was obtained the researcher contacted the head teachers of the schools to discuss the matter further and arrange the visits to the schools.

It should be added here that there was only one type of school used, the public one and moreover, that from secondary education there were not any technical vocational educational schools recruited but only unified upper secondary schools were used. Whilst the use of only one type of school, the public one, and the exclusion of vocational schools would suggest, in terms of the population validity of the study, that it would be difficult to generalise the results of the study, generalisations can be supported to that type of school in which the majority of Greek students are educated. Only of about 65,000 students attend private schools in Greece whereas the total population (Table 3.2) is of about 1,320,000. Moreover, 3 out of 4 students who join upper education choose to attend unified upper secondary to vocational schools.

To ensure that the heterogeneity of social background of the students' population would be represented, from the schools that a relationship of the researcher and the stakeholders existed, those which reflect a population of mixed socio-economic status were selected (the 22 schools which were initially contacted). Also, in terms of the heterogeneity of the sex of the students, albeit the identification of sex differences in students' ideas was not the purpose of this study, it was assumed that the distribution of boys and girls in the classes recruited was similar to that of the Greek population in general.

3.4.6 Review of questioning types

Whilst there is a wide range of types of questioning used to examine students' ideas and the explanations they provide about specific situations and phenomena, two are used most frequently. Open ended approaches based upon qualitative methods and closed approaches, deriving from a quantitative methodology. In order to argue for the questioning approach chosen to be used, the different questioning approaches are examined in the following sub-section indicating why the chosen one serves the purposes of the present study.

3.4.6.1 Closed-choice questions

A closed type of questioning provides the range of answers from which students have to choose. Multiple choice questions and rank order questions have been used in the research of children's ideas about several phenomena (day/night alteration, seasons, condensation/evaporation, electricity etc.) (Baxter, 1989; Bar & Galili, 1994; Summers et al., 1998). In general terms, these types of questions can be answered quickly, straightforwardly and are not related to a student's ability to articulate a response (Wilson & McLean, 1994). In addition, all participants in such surveys are constrained to respond in the same way making the analysis of the answers quick, easy and efficient.

This approach is based upon quantitative methods providing numerical data which are precise due to the form of answers. In contrast to open-ended types where sometimes a substantial amount of word-based information needs to be analysed, closed questions enable comparisons to be made across different groups of respondents (Oppenheim, 1992). As Johnson and Onwuegbuzie (2004) have mentioned, one of the strengths of closed questions, and of quantitative methods in general, is that they are suitable for validating already expressed theories and for testing hypotheses. Also, closed type questions could be used to generate frequencies of answers and tendencies of students' perspectives.

On the other hand, closed questions do not allow any 'freedom' to the respondent to add any comments, remarks and explanations to the options provided. Therefore, as Oppenheim (1992) argued, there is always the risk that the possible answers might not be exhaustive and satisfactory for the participant.

More importantly, another weakness with regards to the limitation of the available answers is the danger of missing out interesting phenomena. If there is a discrepancy between the participant's view and the categories of responses designed and provided by the researcher, the former will probably try to answer the best they can in terms of the available options and, is so doing, the fact that these options do not fully align with their own ideas may be concealed.

As mentioned above rank ordering tasks and multiple choice questions were two of the questioning approaches used in many studies where quantitative methods were employed in the area of a child's ideas and reasoning about phenomena (e.g., Baxter, 1989; Summers et al., 1998).

In rank ordering tasks, a list or categories of statements is provided, and the respondent is asked to indicate an order of some sort, to choose what is more suitable for them and rank it appropriately by identifying priorities (Cohen et al., 2007). Thus, although this is a quantitative method, it could be argued that it enables a relative degree of freedom in terms of priority and preference.

Nevertheless, the respondent has to rank the categories that are predetermined by the researcher. Therefore, participants are constrained to express their perspective using the researcher's list of ideas. Further, even if the researcher has carefully designed the categories allowing possible fine distinctions to be made, the identification of priorities might not be easily perceived or understood by the participant (Cohen et al., 2007).

Another approach, that of multiple choice type of questioning, shares many similarities with rank ordering tasks, in that the participant has to reply according to given statements designed by the researcher. The latter has to design carefully the range of responses so as to record accurately the possible answers given by the participant. The development and the use of multiple choice tests have the potential to contribute valuably to the area of children's misconceptions and can be helpful in identifying their ideas about scientific concepts (Treagust, 1988).

However, this approach cannot reveal in-depth details of students' understanding. Being a quantitative method, it has the benefits mentioned above but care must be exercised when designing the categories so as to offer an exhaustive range of possible answers and avoiding any overlaps of the possible answers (Cohen et al., 2007). Moreover, it is important for the participants to be informed whether they could choose one (single answer mode) or more responses (multiple answer mode). The fact that the list of answers provided could not comprise all the possible answers and thus participants might not have the opportunity to choose their perspective is a major issue of this method.

Several researchers have used multiple choice type of questioning in order to identify students' alternative ideas (e.g., Bar, Zinn & Rubin, 1997; Nobes, Martin & Panagiotaki, 2005; Straatemeier, van der Maas & Jansen, 2008).

Also, there are studies that have used such a questioning method to identify students' reasoning about situations. A typical example is the work conducted by Viennot (e.g., Viennot, 1979, 2001). In one of Viennot's early works students' spontaneous reasoning about phenomena related to the notions of energy, force and motion (Viennot, 1979). The purpose was to focus on students' predictions about situations and pencil-and paper tests, with dichotomous questions (questions that require a 'yes/no' response) were used. However, in order to explore students' thoughts in greater depth students were also asked to provide explanations about their answers for which open-ended questions were used. The following section examines this type of questioning.

3.4.6.2 Open-ended questioning

This approach simply refers to asking a participant of a survey a question in which the latter answers with no restriction. Usually, in questionnaires, space is left after the question for an answer to be provided without any constraints. In the case of interviews participants' responses are audio and/or video recorded. The collected data are in verbal (oral or written) and sometimes in pictorial form. In order to identify students' ideas, both verbal and pictorial data were obtained in open ended questions. As an approach, this type of questioning has distinctive features of qualitative methods (Legard, Keegan & Ward, 2003).

This method can provide an opportunity to gain in-depth information that could not be easily revealed through the use of a solely quantitative approach as the latter lack in ability of taking a full account of the interaction that takes place in social contexts (Cronbach, 1975). Indeed, the key feature of such an approach is the deepened comprehension of phenomena with explorations being conducted in a natural setting while descriptions are being recorded and/or written in such a way that usually result in sufficient details for the researcher to understand the circumstances of the situation (Mesec, 1998). Strauss and Corbin (1990) have also argued that open-ended questioning, being a qualitative approach, can be used for a better understanding of a phenomenon and for gaining new insights about already known things. As Devetak et al. (2010) suggest this could justify the aforementioned shift of science education research from quantitative to qualitative methods.

Based upon the already discussed advantages of this methodology, researchers who used such an approach claimed that the use of open questions has the potential to resolve some of the problems of close choice questioning (e.g., Samarapungavan et al., 1996; Vosniadou, 2002). They explained that they used such an approach in order to gain an in-depth comprehension of their participants' views in as a natural setting as possible (Nobes et al., 2004).

Furthermore, Cohen et al. (2007) stated that such questions also ensure the quality of the response in terms of authenticity, richness and honesty. In this sense, closed-choice questions allow participants to answer only if they understand and interpret the question according to the options provided whereas in open questions the answer is free of such constraints. Of course, this freedom of the participant might also constitute a disadvantage. To illustrate, different respondents might interpret the same words differently, thereby rendering the answers ambiguous (Schuman, 1966).

However, it is the probability of obtaining irrelevant answers that is the core problem of this questioning time as participants might provide unrelated answers to the questions being asked or answers that do not serve the purposes of a certain study. A solution to this problem can be explicit instructions given to participants during the procedure of completing the questionnaire or during the conduction of the interviews.

Another issue related to the use of open-ended questioning is the difficulty in making comparisons between responses (Schuman, 1966). This is because articulate and inarticulate participants reply differently and therefore, there might be less content in common to compare, or because they may be reluctant to read and write for several reasons (Cohen et al., 2007). The source of this problem could be data handling issues, explaining to some extent the fact that it is relatively rare to find very explicit discussions about how to analyse data gathered using such a methodology (Burgess, 1985). This might be because qualitative research is conducted basing upon the principles of the interpretative paradigm, where focus is neither only on examining the subjective experiences of an individual, nor the way that the individual attaches to specific events but also on the subjective perspectives of the researcher of the situation being studied (Devetak et al., 2010).

Cohen et al. (2007) mentioned another data handling issue of open-ended questioning techniques. It might be difficult, though not impossible, to transform the data into numbers in order, for example, to make comparisons between responses given from participants of different groups (age, sex, etc.). As they argued, word-based data are susceptible to combinations and aggregation. Although this transformation of data and combination of methods seems appealing, the researcher by using principles of quantitative methodology alternates the qualitative character of the methods. For instance, especially in the case of interviews, researchers would encourage and/or lead participants to give an answer that could be converted into numbers, aiming to use these numerical methods to conduct the analysis. However, this type of questioning has less features of open-endedness and does not allow participants to respond in their own way. Furthermore, in interview settings, researchers might be accused of asking the same question until they get a numerical answer and thus, of leading their sample towards a desired response, losing the desirable freedom from limitations discussed previously. Hence, statistical and numerical approaches are quite rarely used because, as Bryman (2004) pointed out, the aim in this case is to search for codes (phrases or concepts/notions) in the analysed data.

Moving further, whilst open-ended questioning methods are commonly used in written questionnaires, as it was the case with Viennot's (1979) study, the same methods are also found in research interview settings. An interview differs from a questionnaire in the process of gathering the data and in the way that responses are recorded. Data are collected through oral interaction between the participant and the interviewer whereas in a written questionnaire, respondents should read the question and record their perspective on their own. This might be problematic because respondents may be reluctant to read and write for several reasons (Cohen et al., 2007)

Research interviews have been defined as a conversation between the researcher/interviewer and participants within a study. In many of the studies in which open-ended questioning methods were used in interview settings, semi-structured face to face interviews were conducted, as a versatile and productive way of communication. As Webb and Vulliamy (1996) have argued, interviews are able to generate considerable relevant information within short periods of time making them ideal for the exploration of students' analogical reasoning.

Although, depending to the approach of questioning used, an interview could have the same strengths and weaknesses previously discussed, it differs from a questionnaire as it offers the potential to addresses some of them, like the danger of been given irrelevant or ambiguous answers or that of inarticulate and articulate responses. Also in an interview setting, the interviewer aims at obtaining research-relevant data but more importantly is capable of focusing the interviewee on the content specified by the objectives of the research (Cannel & Kahn, 1968).

Moreover, an interview allows a greater depth of the questions posed due to the continuous interactions of the interviewer and the participants. It also has the potential of a higher response rate because participants can become more interested and actively involved providing more details about their ideas in comparison to a written questionnaire (Oppenheim, 1992).

Amongst studies investigating the generation and use of spontaneous analogies in laboratories the most common approach met in research interview settings is that of open-ended questioning. For example, Cheng and Brown (2010) while exploring conceptual resources that students use in their analogies when trying to familiarise and understand unknown phenomena, used qualitative methods adopting a clinical interview approach proposed by Clement (2000), where participants were individually interviewed and videotaped. Students' verbal responses and non-verbal behaviour were transcribed from the videotapes. Researchers (e.g., Cheng & Brown, 2010) have also asked students to draw their ideas in order to supplement and clarify their verbal explanations. The use of drawing tasks has been criticized on the grounds that young children, being poor artists, are not able of representing their true and actual beliefs and thus, such drawings might lead to misrepresentation of their views (Siegal, Butterworth & Newcombe, 2004). The latter would suggest not using this data collection strategy for students' predictions and explanations about phenomena and thus, this method was decided not to be included in the present study.

A similar research approach to that in the previously mentioned study was adopted by Inagaki and Hatano (1987, 1991). The aim of their study was to some extent similar with that of the present study in that participants were asked to make predictions although, these were related to observable and unobservable attributes of objects (a rabbit, a tulip, a stone and a person were used). In their studies, Inagaki and Hatano (1987, 1991) interviewed 5-6 year-old participants using a semi-structured questionnaire.

Clement (1988) used a similar qualitative method to observe the way that experienced problem solvers approach a situation. The purpose of this study was different to that conducted by Cheng and Brown (2007) and the present one. However, the approach used shares many similarities with the previous one discussed above. Clement (1988) looking into methods for the generation of analogies asked participants to think aloud as much as possible while there were trying to solve the spring problem described in the previous chapter. Clement did not ask any questions during the participants' verbalised thought process but only after they came to an answer, participants were asked to estimate the confidence they had in their own answer and if they could increase it which often led to further work on the problem. Occasionally the interviewer asked questions for clarifications on participants' answers but did not provide any kind of guidance for the generation of analogies.

A similar approach was also used by Wong (1993a, b) who explored the potentiality of self-generated analogies as a tool for explanation of scientific phenomena. Wong's participants were presented with a phenomenon (piston/cylinder device) and they were asked to explain it. Moreover, participants were asked to generate analogies in order to attain a better understanding of the phenomenon. In other words, they were prompted by the researcher to generate analogies. In contrast, participants in Clement's (1988) study, without any provocation, referred to another situation which shared many similar features with the original problem presented to them. Given that the aim of this present study is to examine the way that students of different ages spontaneously answer questions about novel situations, the initial idea was not to provide any kind of lead to the students in order to generate analogies. Although some findings emerged from the pilot study which had a significant impact on this initial idea, it was attempted not to lose the spontaneous self-generation of analogies in students' responses. The latter affected the research strategy as well as the data analysis and the changes made are discussed elsewhere in the present chapter (subsections 3.6.1-3.6.3).

In agreement with the previous studies, Sandifer (2003) used a qualitative approach to collect data investigating spontaneous student-generated analogies. However, the methodology followed was fundamentally different. Students participated in three different sessions two of which were group problem sessions while the other was an individual explaining session. In the first case, participants were asked to work on qualitative and quantitative mechanics-related questions and problems. During the individual explaining sessions, students were asked to explain the concepts of energy and force one-on-one to a student who had never been taught physics.

Different research needs call for different research strategies. The use of qualitative approaches in order to explore spontaneous generation of analogies and their use has basically arisen from the need to obtain more in-depth information about the way that students construct their analogies and what conceptual resources they use for their generation. In many cases the research was a case study (e.g., Sandifer, 2003; Cheng & Brown, 2007) with open-ended questions in an attempt to capture unique features that might otherwise have been lost in a large scale survey with closed-choice questions. Such an approach is appropriate for gaining an in-depth comprehension of participants' ideas and views. It could be argued that this could not be done by using quantitative methods like these described previously.

On the other hand, there are studies that except from interview settings with open questions have also employed closed-choice questions (e.g., Viennot, 1979). This technique was used for validating already known information on students' alternative ideas. In other words it was used to test if participants expressed the same ideas identified in the literature

3.4.7 The research questioning method

It is clear from the aforementioned that each questioning approach has its advantages and disadvantages. However, bringing together the two approaches can be beneficial for a study such as the present. Even researchers, who have claimed that these two approaches are fundamentally different in terms of their ontological and epistemological basis, have argued for the value of an attempt to bring together the two different approaches (Ritchie & Lewis, 2003). A combination of the two methods has the potential to offset their weaknesses and capitalise on the strengths.

From the aforementioned review of the approaches that similar studies followed and taking into consideration their strengths and weaknesses, it was decided to integrate quantitative with qualitative methods in order to serve the needs of this present study and to provide a better and more comprehensive way of answering the research questions going beyond the limitations arising from the use of a single approach.

Thus, the research questions were answered using mixed methods, qualitative and quantitative in order to study the same phenomenon of students' predictions in novel situations, but they are divided in terms of what is being investigated. Quantitative research was used to investigate the predictions that students made aiming at revealing any trends in their responses. Quantitative approach was combined with qualitative inquiry to explore the underlying reasons that might have been the cause of these trends (if any were observed).

Being a mixed method study, a series of semi-structured group interviews/discussions were carried out in combination with the administration of a paper-and-pencil survey. Students were asked to make predictions about certain phenomena and provide explanations about them. The data collection involved two phases. At first a mixed questionnaire with open-ended and multiple choice questions was administered to the students and subsequently, after dividing students into equal groups, semi-structured interviews took place.

In order to achieve the aims of the research, a six-item questionnaire was designed. For each item, the questionnaire was divided in two sections including a closed and an open question. The first question, the closed-choice one, was a multiple choice question asking students to make a prediction for a situation presented to them in a pictorial form (reasons for presenting the novel situations in a pictorial form are discussed in subsection 3.5.1) and the other one was an open-ended question asking students to explain their predictions. The same pattern was followed throughout the six items but further details about the construction of the questionnaire are provided in the following section.

Being a cross-age study, a closed-choice question constitutes an appropriate approach for this research enabling comparisons to be made across groups within the sample. As Oppenheim (1992) argued a closed questioning approach ensures that answers of several groups can easily be compared and that all respondents give their answers after having considered the content.

Moreover, having the characteristics of quantitative methodology, a closed-choice question is a very attractive approach for large samples, such as in the present study. Here this closed approach was used to generate frequencies of answers in an attempt to identify any possible tendencies of students' perspectives and predictions on the phenomena presented to them. The aim of the first question was to capture the likely range of responses to the given options of predictions and, in this way, obtain a first insight into students' ideas and knowledge about the situation. In this case, as Cohen et al. (2007) argued, this type of questioning is the appropriate one as it enables the observation of patterns, despite the many weaknesses discussed above.

In order to eliminate these problems, and also to achieve a better understanding of particular phenomena (Strauss & Corbin, 1990) the first question was followed by the use of an open-ended question. Students were asked to provide explanations about their predictions. In the second question there was an opportunity for students to provide any alternative answer not included in the multiple choice list. Additionally, participants could add any comments and remarks related with the options provide in the multiple choice question, limiting this way the disadvantages of the first multiple choice question allowing much freedom to the respondent to write an answer in their own words and terms. Basing upon the assumption that they will construct their explanations using analogies, the basic purpose of these questions was to identify students' spontaneous and self-generated analogies.

As such, interviews were carried out with the students in order to explore further the way they justified and explained their predictions ensuring at the same time that the responses would be helpful in answering the research questions of this present study. Indeed, the use of interviews for collecting survey data is a useful approach in the sense that the presence of the researcher can facilitate the clarification of participants' queries so as not to deliver irrelevant answers. Unarguably, in an interview setting the researcher can stimulate the respondent to give full and complete answers (Robson, 1993). Furthermore, according to Bailey (1994) interviews can be flexible in the sense that questioners are able both to probe and explain more efficiently, especially when exploring the generation and use of analogies (e.g., Clement, 1988; Cheng & Brown, 2007).

There is also evidence that face-to-face encounters improve response rates. This could be done by using non-verbal behaviour during the interview to encourage students to participate and elaborate more on their explanations (Cohen et al., 2007). Even when students do not answer the open-ended question in the questionnaire, there are opportunities for the researcher to encourage students provide a justification for their answer and therefore for further investigation.

In this present study, interviews were considered appropriate for two additional reasons. Firstly, because it would make easier to tell whether the situation presented to students was new to them as they were asked about it during the interview. Secondly, because the need to identify students' way of thinking underlying their responses in order to examine what made them respond this way would, arguably, have been more difficult to achieve using questionnaires only.

Continuing, semi-structured face to face group interviews were conducted as being one of the most versatile and productive methods of communication and also an attractive approach for the needs of the present study considering that this is a cross-section study of a large study sample. Individual interviews are found to be lengthier than group interviews which are essentially quicker to carry out and timesaving (Oppenheim, 1992). Another advantage of this type of interview is the opportunity to bring together students with varied opinions and different ideas.

Arksey and Knight (1999) suggested that during a group interview the participants can complement one another, make additional points and encourage each other providing this way fully and more reliable answers. Also, students support and influence one another, agree or disagree with each other encouraging thus active participation of all those present. Evidence provided by Sandifer (2003) suggests that the self-generation of analogies by several students in group discussions trigger others to produce their own analogies. This indicates that it might be fruitful to collect the data in group interview settings because this process can help students interact and self-generate analogies.

On the other hand, Cohen et al. (2007) have argued that features that make this type of interview attractive might also make it problematic. For one there is the possibility of one participant dominating the discussion a problem that met when there is an overrepresentation of males (Arksey & Knight, 1999). To avoid this issue, students in this study were divided into as many groups as possible with equal representation of males and females.

Another strategy followed to limit this weakness was for the researcher to moderate the discussion to ensure that all the members of the group were able to contribute. Participants who were observed to hold a different view from the dominant one within the group were encouraged by the researcher to give their personal response and express their opinion. The aim here was to create a friendly environment and help all students to give their personal justification about the option they had chosen in the forced-choice question, collecting as many analogies as possible and avoiding this way capturing what Cohen et al. (2007) named as the “group think” (p. 373).

Also, by choosing to follow the strategy mentioned in the previous paragraph, it was attempted to ensure that the data gathered was of high validity level. This was done by facilitating the relationship with the students, minimizing at the same time any reactivity effects, i.e. differences in participants’ behaviour due to their position in an interview setting where they are subjected to scrutiny (Cohen et al., 2007).

In order to encourage the students to provide rich responses and make them at the same time feel confident about their predictions they were initially given background information about the purpose of the study. This was also an ethical requirement but ethical issues are discussed separately within this present chapter (section 3.7). The aim was to explain to them that during the interviews the interviewer was not concerned so much about whether their predictions were correct or not, but rather it was emphasized that it was the way they justify and explain their predictions that was of special interest. The researcher did not provide any evaluative or substantive comments about students' predictions and explanations of the latter but only provided general encouragement.

The initial idea was that only two questions ('Why do you think this will happen?', 'What makes you think that?') were to be used during the interview so as not to prompt, in any sense, the generation of analogies by the students, capturing this way their spontaneity, however, emergent issues from the pilot studies suggested some changes discussed in section 3.6, needed to be made.

In order to record accurately the group discussions, the initial idea was that the group discussions would be video recorded. Video can be beneficial for the researcher as it reveals the unnoticed details and catches non-verbal communication providing this way richer data (Erickson, 1992). This is a common technique used to record students' predictions and explanations and it was used in several studies that investigated the generation of analogies (e.g., Clement, 1988; Wong, 1993b). Whilst the use of video recording was initially considered the researcher was informed that the Greek Ministry of Education would not give the consent to the use of such a technique.

A video recording method to collect information in interview settings within a classroom is believed to achieve a high degree of ecological validity in the level of data collection. Ecological validity, a concept initially developed by Bracht and Glass (1968), like population validity, is one of the factors that can enhance the external validity of a research, i.e. the degree to which the findings of a study can be generalised to the whole population (Ritchie & Lewis, 2003). As Cohen and Manion (1982) noted ecological validity relates to generalizability in the sense that it considers the conditions, like the treatments and settings, in which the results of a study carried out in a particular environment were obtained and might be expected to be found in another similar case.

However, the use of a digital camera to record students' responses during the group discussions was found to be disruptive due to issues of ethics (discussed in section3.7). Therefore, taking into consideration the previously mentioned issues of access, whilst seeking to maintain the high level of ecological validity, the decision made was to audio-record the group-interviews with the interviewer describing as many details as possible before, during and after the conduction of the interviews with the tape recorder being turned on. Also, during the interviews, it was decided to leave the tape recorder at the centre of the group in order to record at the same time all the interviewees. What follows in the next sub-section is the design of the research instrument and the novel situations included.

3.5 The Research instrument

Existing research literature has addressed the issue of students' predictions and explanations about various phenomena revealing, this way, their ideas and understanding. Topics like children's ideas and understanding of the notions of different substances (e.g., Bar & Travis, 1991), changes of states of substances, like water (Brody, 1993), conceptions of force and motion (e.g., McDermott, 1984; Finegold & Gorsky, 1991) and familiar astronomical events like the Earth as a celestial object (e.g., Nussbaum, 1985) are well studied. Similar concepts were used in the construction of the study research instrument. However, what is different in the present study is the way the concepts were presented to the students. The concepts were presented to the students using novel situations: novel in the sense that it was reasonable to expect that students would never have considered or been asked to provide an explanation for before.

Attention was paid to ensure the clarity of the novel situations for all students across the five age groups participated in the study. The situations were designed in such a way so as to be comprehensible for students from primary to upper secondary education ensuring at the same time that students provide relevant answers to the purpose of the study. Bliss and Ogborn (1993) have argued that demanding from participants clear and detailed statements about something that is obvious is a difficult issue because these things usually remain unsaid. Especially for the students who will rely on common sense to answer the questions, there is a possibility that they might find the answers obvious with no need for further explanation. In this case it will be difficult to elicit their responses and more difficult to reveal the underlying reason for thinking and explaining this way the situation. Therefore, the novel situations were not either very complex or too simple so that the participants of the study find would find it reasonable to make a prediction and explain them. A pilot study (discussed in section 3.6) was conducted to determine whether this was the case with the novel situations designed in the present study.

The concepts chosen to be used in the construction of the novel situations were selected from different areas of science. They come from areas that have been studied in terms of misconceptions and p-prims. Further details about the selection the concepts in each situation and the situations constructed are provided in the following subsections.

3.5.1 Novel situations in pictorial form

The novel situations were presented in pictorial form followed by a closed-choice question. In a separate sheet, students were asked to explain their answer ('what makes you think that?') (see Appendix G). With images playing an important role in memory (Marks, 1973) and being able to enhance students' recall of information (Purkel & Bornstein, 1980), it was decided to present the questions in a pictorial form. Following the well-known adage, "A picture is worth a thousand words" (Banikowski & Mehring, 1999, p.10), the use of pictures can serve as a memory support reducing the amount of information needing to be stored in the working memory -i.e. that system of the mind in which multiple pieces of information are held and where they can be manipulated- whilst the question is being answered. Several studies have demonstrated these advantages of the use of pictures (e.g., Shepard, 1967; Paivio, 1971) or motion pictures (Spangenberg, 1973; Booher, 1975) over words arguing that the formers can provide a greater amount and diversity of information in comparison to the latter. For example, as Fleming (1979) wrote, a drawing of a house can provide more 'hooks' for memory in comparison to the printed word 'house'. This is because, according to Reznick (1977), a picture of a house is relatively unique for the individual (it has been encountered rarely, if at all) whereas the written/printed name house is relatively common (has been encountered more times) and as such is less individually memorable.

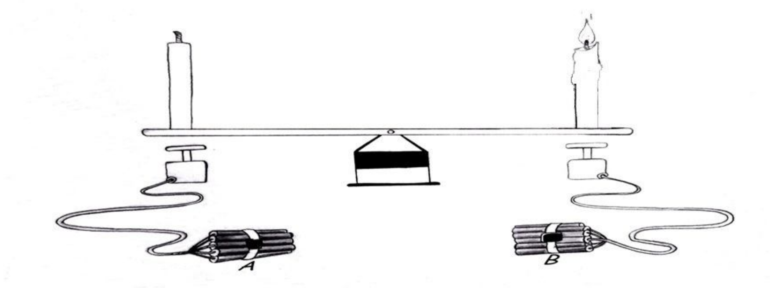
Pictures also offer the opportunity to develop and communicate connections between what is being seen and what is stored in memory (Kaplan & Howes, 2004). Similarly, pictures can be linked with activities and places providing a visual context which can support memory retrieval. According to Miles, Kaplan and Howes's (2007), the use of pictures in a study has the potential to "represent, engage and influence" (p.1) more effectively than traditional written questions. Additionally, as Banikowski and Mehring (1999) argued, the use of pictures allows prior knowledge of a situation held by students to influence their understanding of something new. Such use of pictures can be valuable in identifying students' ideas when they are trying to understand and make their predictions in the novel situations.

Therefore, the use of a combination of pictures and written material was deemed appropriate in the present study as it offers the potential to provide explicitness, facilitate comprehension and reinforce validity of findings where using solely written materials has been reported to lead in many cases to ambiguous or even contradictory findings (Bock & Milz, 1977).

Several reasons led to the use of two common design features in the presentation of the pictorial novel situations, one of which was bombs connected with a detonator and the other was arrows pointing at options. The aim was to encourage students to express their own ideas, to elaborate on their thoughts regarding their choices and to discourage them from building their answers and explanations by using phrases and terms found in the questions. Hence, in the first case students were asked which bomb would explode (or which would be the first to explode) with each of the possible answers representing a different possible prediction. Arrows were used likewise as students were asked which of the arrows depicts the point that describes the correct answer.

The use of the two design features is made clearer in the following section where the novel situations are presented. What follows is a presentation of these pictorial questions, as they appeared when presented to students, along with some comments for each of them concerning what has been found in other studies that have dealt with similar concepts. It should be explained here that the questionnaires were translated into the Greek language and also that the interviews were conducted in the Greek language for the students to be able to comprehend and participate in the discussions. Later, when the data were being transcribed the aforementioned were translated back into English and for the level of validity to remain high an external translator was recruited. This person retranslated all transcripts and questionnaires collected and later the two versions were collated and discussed. No significant variations were noted between the two versions.

3.5.2 Novel situation 1: Burning a candle



Two identical candles are balanced on a beam. After, we light one of the candles as shown in the figure. Will one of the bombs explode? If the answer is yes, which one of the two will?

A) None of the bombs will explode B) Bomb A will explode

C) Bomb B will explode

Figure 3.5.2 Novel situation 1

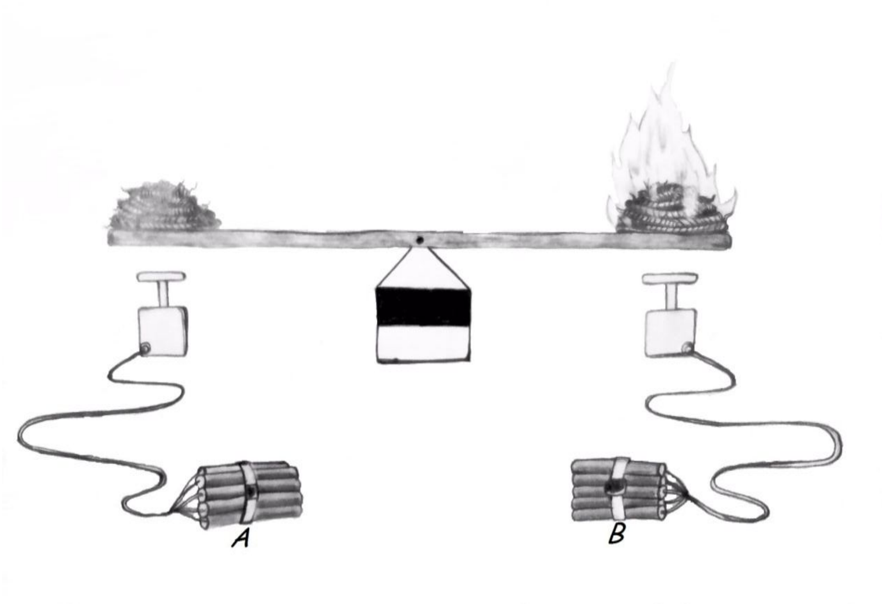
This novel situation explored students' ideas about what happens to the weight of objects when they are set on fire. Figure 3.5.2 above shows the pictorial form of the question. The options were presented to the students by the use of bombs tied at the end of a wire being connected with two buttons, as the design feature, asking the students to indicate which of the out of the two bombs would be set off after the candle on the right would be lit, indicating that there is a change of weight balance or if it would be the case that none of them would set off indicating that the beam will continue to balance even after the process of combustion has taken place. Several researchers have investigated students' ideas about combustion (e.g., BouJaoude, 1991; Watson, Prieto & Dillon, 1997). Similar response patterns were revealed in both studies of BouJaoude (1991) and Watson et al. (1977) when students were asked to explain what happens to a candle when it burns and where findings suggest that a number of students aged from 11 to 14 years understand candle burning as a change of state (Meheut, Saltiel & Tiberghien, 1985; BouJaoude, 1991) with younger students simply describing the process as something being melted.

As Kind (2004) argued, key concepts that might contribute to the understanding of the candle burning process are the role of oxygen and the particulate model of matter. According to the scientific point of view, the carbon particles in the candle react with the oxygen in the air to make carbon dioxide. Subsequently this gas (CO_2) is given off and therefore the remaining candle weighs less than before being lit (further details about the reaction are given in the Appendix A).

Previous research (Watson et al., 1977; Meheut et al., 1985; BouJaoude, 1991) has shown that although students know that oxygen is necessary for burning they cannot describe the role of oxygen in the burning process. Students of 11 and 12 years of age explained candle burning involving statements such as the oxygen is being burnt or used up (Meheut et al., 1985) whereas older students (14 years old) claimed that "oxygen feeds the fire and keeps the candle burning" (BouJaoude, 1991, p. 695). Students who lack an understanding of the role of oxygen in the burning process, as well as the fact that the oxygen is invisible, can often be misled to claim that only state change takes place and therefore their senses suggest that it is the heat from the flame that causes the candle to melt.

The poor particulate model of matter that some students hold explains why the flame or the wax could not be perceived as something being particulate in nature causing the inability to explain what happens to the mass of the candle as it burns. Thus, students may think that the candle mass decreases due to the evaporation of wax. Nevertheless, Samarapungavan and Wiers (1997) have argued that it is likely for students being confronted with such a situation for the first time to generate predictions by using their prior observations of objects being burned.

3.5.3 Novel situation 2: Burning iron wool



Two wire sponges which have the same weight are balanced on a beam. After, we light up one of them. Will one of the bombs explode? If yes, which one of them?

A) None of the bombs will explode B) Bomb A will explode

C) Bomb B will explode

Figure 3.5.3 Novel situation 2

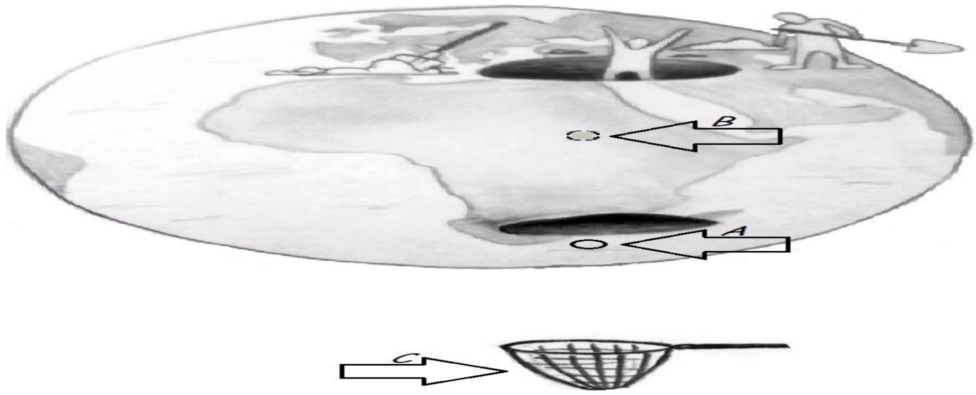
Figure 3.5.3 above shows the pictorial form of the question and that the options were presented by the use of bombs tied at the end of a wire being connected with two buttons, as the design feature, asking the students to indicate which of the two bombs would be set off after the iron wool will be burnt or if it would be the case that none of them would, indicating that the beam will continue to balance. It should be noted here that when chemists say the iron is being combusted or burned, what is meant is the application of heat which actually increases the rate of reaction between oxygen and the iron wool. In that sense this situation is different from the previous one in which there was the presence of flame during the burning of the candle. However, students were asked to predict how the mass of the iron wool would change once burnt in oxygen (similar prediction to the previous novel situation) hence, taking into consideration the aforementioned, students were expected to reason in the same way as they would have in novel situation 1.

Children's views about the burning or the combustion of iron wool have been reported by several researchers (e.g., Driver et al., 1985). A very similar question about the burning of iron wool has been used by Driver et al. (1985) with a group of 11, 12 and 15-year-old students. An image showing two pans of a scale with iron wool in the first one and equal weight in the other so as for the scale to be balanced was presented to the students. The latter were asked to predict what it is expected to happen to the first pan if the iron wool is removed, heated in the air and then the black formed powder created is returned into the pan. Over a quarter of the 12-year-old students claimed that the mass of the iron would remain unchanged. Their basic argument is that the remaining ash is still the same iron wool and therefore they cannot see any reason that may change the iron wool mass. Driver et al. (1985) have however found that a small a ratio of 15-year-old students has predicted, in a similar experiment, that the iron wool would be heavier aster being burnt, yet only a few of them were able to provide the scientifically correct reason for their predictions which actually is that the ash of the iron wool has encountered oxygen during the burning process and thus, this would add to its weight (see appendix B).

In a similar study, Barker (1990) reported that few students aged 11 and 12 years suggested that one substance can change into another that weighs more. In this case, the iron wool that burned changed into carbon which weighs more. As Kind (2004) commented, this idea can perhaps be based on students' experiences of burning fuels which is known to contain carbon. In this case, students gave the right answer but the explanation provided was scientifically inaccurate. Similar responses with that revealed by Barker (1990) were identified by Andersson (1986) with a different age group. 15-year-olds in Andersson's (1986) study did use the idea that the iron wool could be turned into carbon which is lighter and therefore their claim was that there would be a mass decrease.

As it has been hypothesised from the previous novel situation (5.3.2) students' everyday experiences of objects burning leaving behind light ash can lead them to display the idea that the burning piece of wire wool becomes lighter. Nevertheless, as it mentioned above, what actually happens is much more different. The mass of iron wool would change once it is burnt in oxygen (or combusted in oxygen). In sharp contrast with the previous situation, the mass of iron would increase and therefore, the correct prediction is that bomb B will be activated. Whether students of the present study hold similar ideas with those reported in the aforementioned studies about the combustion of iron wool as well as where these ideas might stem from will be discussed further in the study.

3.5.4 Novel situation 3: Objects falling in holes dug into the Earth



Two people have dug a huge tunnel straight down from the one side of the Earth to the other (as shown in the figure) and one of them jumps in. Where will this person stop?

A) On the other side of the tunnel B) In the middle of the tunnel

C) In the net

Figure 3.5.4 Novel situation 3

In this novel situation the options that students were provided with were that either the person would fall towards the other side of the tunnel (A), or that the person would stop falling in the middle of the tunnel (B), or that the person will end up falling in the net being set under the exit point (C). Figure 3.5.4 above shows the pictorial form of the question and that the options were depicted by the use of arrows as the design feature pointing at the exact point that each of the three options respectively represent. This was done so as to avoid confusing students and let them explain their thinking underlying their predictions without straightforwardly asking them about the notion of gravity. In this novel situation both options A and C are wrong without any fundamental difference in which they would have been closer to the scientific explanation and students were expected to predict that the person who jumped in the hole would stop either in the net or at the other side of the tunnel.

What is examined with this novel situation is the idea that students hold about the notion of gravity in combination with the ways in which down or downwards is interpreted. A considerable amount of work has been directed towards students' views about the Earth as a cosmic body exploring at the same time their ideas about what they mean by downwards and down (e.g., Nussbaum, 1985; Vosniadou & Brewer, 1990).

In two studies (Nussbaum, 1979; Nussbaum & Sharoni-Dagan, 1983), Nussbaum investigated the development of the Earth concept and related phenomena. This was done by conducting interviews with students from grades two, four, six and eight aged 8, 10, 12 and 14 years respectively. Most of the students (70%) in grade 8 demonstrated the understanding that people live in a spherical planet with space all around it. They also were able to relate falling toward the Earth with gravity. However, 20 % of them seemed to explain this falling as being related to the Earth as a whole and were not able to relate directions to the centre of the Earth.

In these two studies, younger students could not understand the shape of the Earth proposing different models like a flat Earth (50% of students in year four, almost equal percentage of students in year two and about 20% of students in year six), a huge ball Earth with two hemispheres with people living in the lower one (40% of students in year two, around 15% of students in years four and six) and a spherical solid Earth without however using the planet as the frame of reference for upwards and downwards directions (almost equal percentage of about 25% of students in year four, six and eight were identified holding this view). The ideas that students expressed about the shape of the Earth influenced the way students interpreted the meaning of downwards. In the same study, they were asked to draw where a rock is going to go if it is dropped in a huge hole dug into the Earth. This question shares some similarities with the novel situation 3 discussed here. The figure below (Figure 3.5.5) presents students' ideas concerning this question.

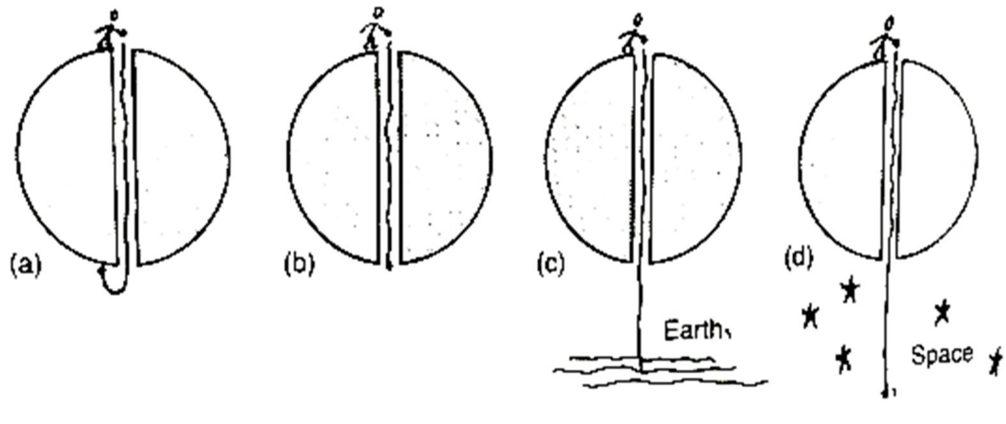


Figure 3.5.5 Predictions of a free-fall through the Earth typical to the idea of a spherical Earth (a or b), a flat Earth (c) and a huge ball and/or spherical solid Earth (d). Source: Nussbaum (1985, p. 184).

In the same study, in another question, students were presented with a spherical Earth with two holes starting from the same point but each one going to different directions. Students were asked to draw the direction of a falling rock into the hole. The figure below (Figure 3.5.7) presents the representative answers of students that hold a scientific correct view of the Earth as a sphere but did respond wrong to the latter question about the direction of a falling rock. Figure 3.5.6 shows the correct answer provided by very few students in year four and six and half of the older students in the study (14 years old).

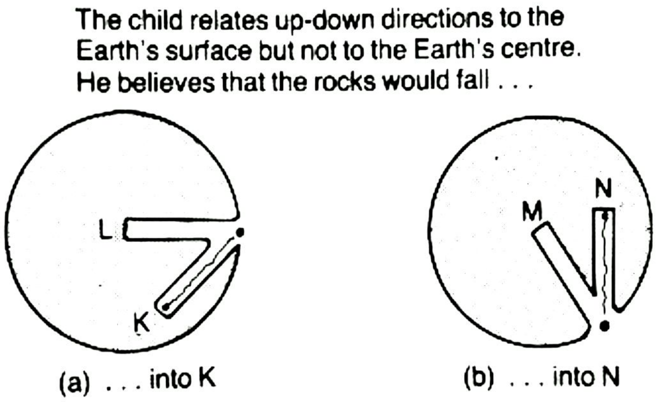


Figure 3.5.6 Representative answers given by students for the falling rock task. Source: Nussbaum (1985, p. 185).

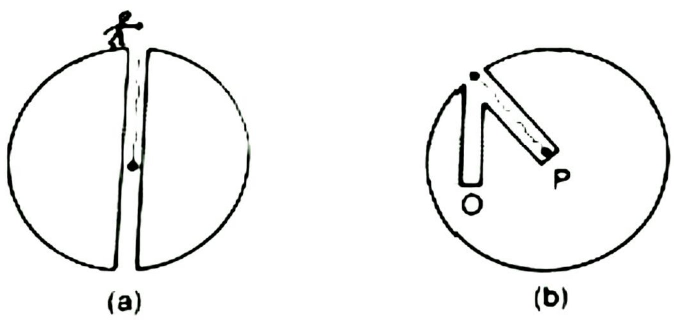
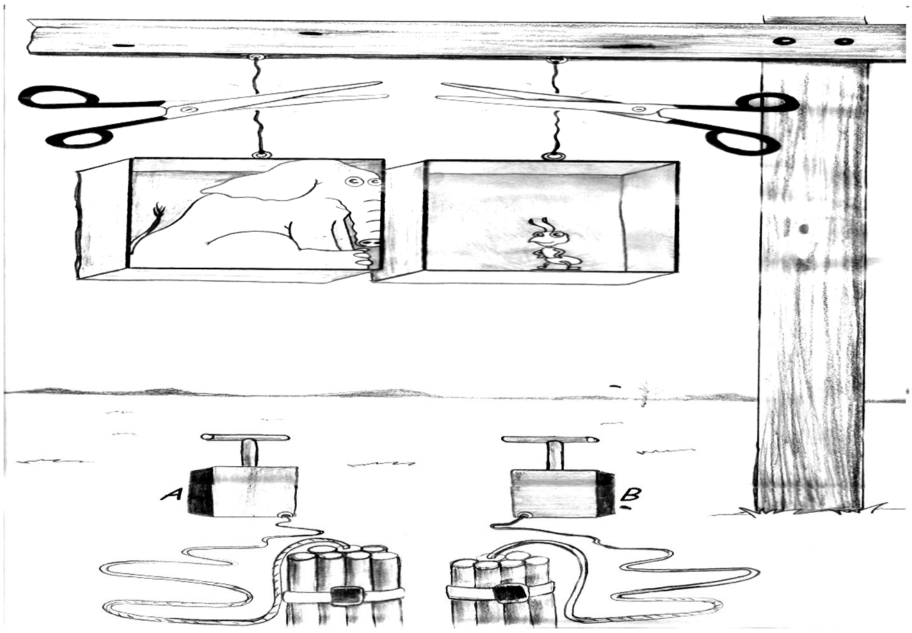


Figure 3.5.7 Representative answer of students responding correctly to the falling rock task. Source: Nussbaum (1985, p. 186).

From the aforementioned and as Nussbaum (1985) commented, there appears to be a progression in understanding, from an absolute view of down not being related to the Earth, to an Earth-referenced understanding of downwards. This is the scientific position according to which the person stops in the middle of the Earth (see Appendix C).

Studies with similar topics such as Mali and Howe (1979), Sneider and Pulos (1983), Baxter (1989), and Vosniadou and Brewer (1990) conducting similar studies in different countries, confirmed this possible progression of ideas from an absolute view of down connected with a flat Earth to a spherical Earth and a scientifically accepted view of down being related to a direction towards the centre of the Earth. The present study compares not only the ideas Greek students expressed in their explanations in relation to those identified in the literature but also the underlying reasoning of their predictions.

3.5.5 Novel situation 4: Weight and gravity



If the ropes shown in the figure are cut at the same time, will the bombs explode at the same time or will one of them explode first?

A) Bombs will explode at the same time B) Bomb A will explode first

C) Bomb B will explode first

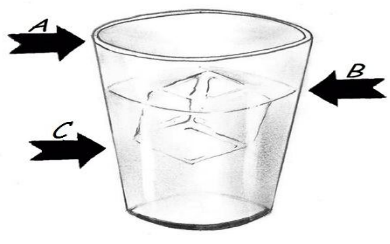
Figure 3.5.8 Novel situation 4

In this novel situation, ideas of gravity that students hold are investigated. To some extent, gravity concept was examined in the previous novel situation but in different context. The difference in this situation is that it examines the meaning of gravity in conjunction with falling and weight and how these are interpreted by the students in an attempt to make a prediction. Figure 3.5.5 above shows the pictorial form of the question and that the options were depicted by the use of explosive bombs as the design feature being tied to triggers lying underneath the two boxes which contain an elephant and an ant respectively. Again in this novel situation the options that students were provided with were that either that both bombs would explode simultaneously (A), or that the first one (bomb A) would go firsts (B), or that the second one (bomb B) would be the first to explode (C) allowing students to choose which of the two boxes hanging above them was more likely to fall faster and to elaborate (later during the group interviews) on what make them pick their choice. Students were expected in this novel situation to reflect upon the concept of gravity and the fall of objects and the pictorial form of the question aimed exactly in stimulating them to develop their own thinking and elaborate on the reasons which led them to make their predictions.

The concept of gravity has been the subject of extensive research. In this research, the naive idea that things fall straight down when released became known in the literature as the straight-down idea. According to this idea, weight causes the falling of objects which stops in the presence of a barrier, and that heavier things fall faster was reported by several researchers (Selman, Krupa, Stone & Jacquette, 1982; Osborne, 1984). As it happens in the previous novel situation, there appears to be a progression from the view that objects fall if there is nothing to support them through the idea that objects fall due to their weight and to the idea that weight is a force that cause objects to fall in the absence of something holding or supporting them (Driver et al., 1993).

The scientific prediction in the present novel situation of this study is that both bombs will explode at the same time because gravity acceleration is constant for both weights (further details are given in the appendix D). However, basing on the aforementioned, students were expected to predict that bomb A would be activated indicating that the box with the elephant would have fallen fall faster to that containing the ant. Whether the discoveries support this assumption will however be discussed further in the study along with the ideas students expressed in their explanations.

3.5.6. Novel situation 5: Melting an ice cube in a glass of water



When the ice-cube melts, which of the three arrows will point at about the same level as the water level in the glass?

A) Arrow A B) Arrow B C) Arrow C

Figure 3.5.9 Novel situation 5

In this situation ideas that students hold about volume, mass and density are examined in conjunction with views about floating. Figure 3.5.9 above shows the pictorial form of the question and that the options were depicted by the use of arrows as the design feature pointing to the possible answers represented by the three options following the picture. This novel situation asked students to choose which of the three arrows indicates the correct level of water in the glass after the melting of the ice-cube contained.

The situation can be easily explained basing on Archimedes' principle which describes buoyancy (or upthrust), the upward force exerted by a fluid, that opposes the weight of an immersed thing in combination with Newton's first law (if the net force is zero, then the velocity of the object is constant). According to Archimedes' principle an object being immersed in a liquid experiences an upward force which is equal to the mass of the fluid being displaced by the object. In case of the weight of the object being greater than the weight of displaced fluid, it floats. If the two are equal, it is suspended, neither sinking nor floating. For instance, when an object is placed in water, it displaces its own volume of water, and that water pushes back against it proportionally, producing an upward force. In this case the ice cube floats and therefore it displaces its own weight of fluid. As much is the mass of the ice cube we put in the glass, equal mass of water is displaced. Essentially, as the mass of ice reduces, less water is being displaced. Equating the upthrust exerted on the ice cube with the weight of it, it can be easily proved that the volume before the ice cube being melted and after remains the same (a detailed analysis is given in the appendix E). Therefore the scientifically accepted prediction is option B.

Cosgrove and Osborne (1981) investigated 8-17 years olds' ideas about ice melting and they found that a commonly expressed idea is that the ice cube just melts and changes into water. In the context of this novel situation, this idea would imply that when the ice cube melts there is a change in the volume it occupies and that there is an amount of water (that coming from the ice cube) added in the glass causing a change in the volume of water. This way of reasoning is an indication of mass being confused with volume which indeed has been reported by several authors (e.g., Driver et al., 1993). The results of the study showed whether the participants of the study hold similar ideas as well as what made them think that way and make their predictions.

3.5.7 Novel situation 6: The boat with the fan

When the fan is turned on which point will the arrow aim at?

A) Point A B) Point B C) Point C

Figure 3.5.10 Novel situation 6

In this novel situation students were asked to decide whether the boat would begin to move after the fan located on it would be turned on. This was done by asking them to choose towards which side the nailed on the side of the boat arrow would turn (if it should). Figure 3.5.10 above shows the pictorial form of the question and that the options were depicted by the use of arrows as the design feature pointing to the possible answers represented by the three options following the picture. This novel situation asked students to choose which of the three arrows indicates the correct direction of the arrow given the state that the boat would be found in.

From a scientific perspective, forces in nature always appear in pairs meaning that for every action there is an equal and opposite reaction. A typical example that of a cup being placed on a table thus exerting a force on the table the reaction of which is an equal and opposite force being exerted from the table to the cup.

In particular in this novel situation, what is examined is the perception of whether the action and reaction of a two bodies system that interact could, being inner forces, to move the system. There are two forces applied to the boat: One from the sail to the right and one from the fan to the left. These forces have a resultant force equal to zero and thus the boat cannot move.

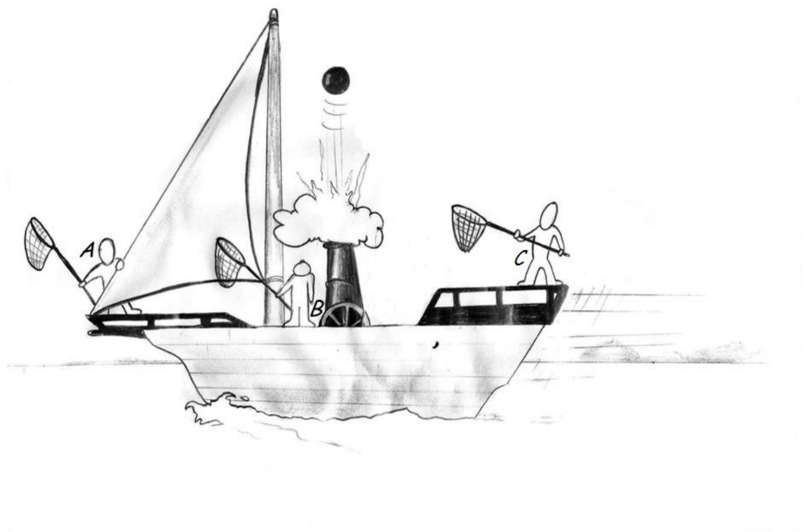
Several research studies (e.g., Erickson & Hobb, 1978; Sjoberg & Lie, 1981) have found that students understand forces as being property of a single object rather than coming in pairs. The reaction of a force is not generally recognised. This has been reported by Erickson and Hobb (1978) and it is also supported by a research carried out by Sjoberg and Lie (1981). In the first study, only around 30% of the students aged from 12 to 14 were able to appreciate the reaction exerted on a fixed string when being pulled by a weight. In the same study, exploring students' ideas about equilibrium, it was found that only around 19% of students between 6-14 years old made reference to a force of reaction whereas they were able to make a distinction between holding and pulling.

Difficulty to recognise the reaction of a force has been noted among high school students and even physics and engineering students. For instance, Brown and Clement (1987), investigating high school students' ideas about collision came to the conclusion that students cannot recognise the reaction during the collision and that they do think of one object (the moving or the faster moving one) as having the more force despite the forces being equal. Minstrell (1982) found that of about 40% of the high school study sample involved the analogy of an upward force from a table to a book being placed upon it. More importantly, even after being taught about the reaction of the force that the book exerts on the table, students were describing this force as something being in the way of the book. Similar ideas were revealed by Clement's (1982) study of pre-engineering students.

As Terry, Jerry and Hurford (1985) argued, this confusion and difficulty might be arising from the way that scientists use the word opposite and reaction in the context of forces appearing in pairs. The latter word seems to suggest that there is a sequence of events in which one force causes the appearance of the other. The word opposite appears to make students think that a reaction forces acts on the same object rather than understand them as two forces being involved in an interaction between two different things.

As aforementioned literature review of related situations makes apparent, it might be difficult even for undergraduate physics students to explain this situation deeming this novel situation too demanding. On the other hand, it is not expected from students participating in the present research to give the 'correct' answers. In other words, it is not attempted to understand the conceptualization of the physics law like the 3rd Newton's law in these situations presented here, but it is rather attempted to investigate how students will reason about the situation and what analogies they will use in their explanations.

3.5.8 Novel situation 7: A firing cannon in a moving boat



While the ship keeps on moving at the same speed, the cannon fires a ball (as the figure shows). Which person is more likely to catch the ball?

A) Person A B) Person B C) Person C

Figure 3.5.11 Novel situation 7

In this novel situation, students' understanding of motion is examined. Figure 3.5.11 above shows the pictorial form of the question and that the options were depicted by the use of three persons as the design feature pointing to the possible answers represented by the three options following the picture. Students are asked to choose among the three persons who is more likely to catch the ball as it will be returning downwards.

This novel situation about intuitive physics is similar to examples such as that of a cannonball being released from the top of the mast of a ship discussed by Galileo Galilei in the book Dialogue concerning the two chief world systems in 1632 (Finocchiaro, 2014). The topic has received great interest and has been the subject of considerable research in the area of science education (e.g., Jira & McCloskey, 1980; Bliss, Ogborn & Whitelock, 1989). It appears that one of the most common ideas among students is that there should be a constant force for motion to be produced (Driver et al., 1993). In the context of this novel situation such an idea would imply that the ball actually drops straight down. In doing so, it falls directly to the point where the cannon released it without taking into consideration the velocity that the boat possesses. Thus, as the boat continues moving, the ball is going to fall behind the cannon. This idea could possibly have its origins in everyday experiences starting from birth onwards which suggest and reinforce the idea that motion is the outcome of a force.

In order for the scientific prediction to be made, students should have grasped the Newtonian idea that there is no need for a causal explanation of a moving object at a constant velocity. What actually happens in this case is that as the cannon-ball starts moving already possessing the forward motion of the boat, it conserves this momentum as it moves upwards and downwards. Therefore, the correct prediction would be that person B is more likely to catch the ball (see, also, appendix F).

Findings of the present study show how students explained their predictions and reason as well as how they perceived the whole motion of the cannon-ball.

3.6 A pilot phase

Before obtaining access to the schools selected for the conduction of the research, it was decided to undertake a pilot study with a smaller sample. As Oppenheim (1992) argues, a pilot has numerous different and important functions. There were several reasons that led to undertaking a pilot study.

The pilot study was principally undertaken in order to increase the validity, reliability and practicability of the questionnaire. Cohen et al. (2007) suggested that everything about a questionnaire should be piloted to ensure the clarity of the questionnaire items and the time required for students to complete it. Students who took part in the pilot phase were asked about the clearness of the questions and to suggest any changes in the phrasing.

In addition, students and their teachers were asked to comment on the layout of the questionnaire with the former being asked about the pictorial form of the questions, i.e. if they were clear and if they liked them. Teachers' opinion was asked with regards the content of the questions and any suggestions they could make to improve them as well as whether there was any kind of lead provided to the students through either the phrasing or the particular form (pictorial, followed by closed-choice question) of the questions. In addition, they were asked to comment if there were any elements that could amount to any bias, making the questionnaire appealing more to some students and being less attractive for others (e.g., more attractive to boys than girls).

The students were also asked about the content of the questions and whether they felt they were too easy or too difficult for them as well as the complexity of the questions in relation to their experiences.

The pilot study was undertaken with the aim of gathering feedback on the validity of the questionnaire in terms of the operationalization of the purposes of the research. What was tested was the functionality of the research instrument in terms of measuring what it was purported to measure. For example, it was checked whether students were explaining their predictions on the basis of their ideas (incorrect or correct, if any, ones) expressing at the same time the reasoning behind their answers. Also, by trying out the questionnaire, the researcher had the opportunity to test the classification system (this is examined below in section 3.8) developed for the data analysis. By checking all the aforementioned issues related to the research instrument it was hoped to achieve a higher degree of assurance of validity in the questionnaire.

Another important reason for carrying out the pilot study was to investigate certain procedural issues concerning practicalities of conducting a research in a classroom setting. These issues included an attempt to gain experience in conducting group-interviews with students and the evaluation the effectiveness of the audio-tape recording system within the noisy setting of a classroom. Finally, whilst the initial research questions had emerged from the literature review, another reason for conducting this pilot study was to have a first insight in students' responses. Basing upon these preliminary data from the pilot study, research questions could be refined and/or modified so as to better reflect contemporary cases (Yin, 2003).

This pilot study was an opportunistic one as well. The process required to receive permission from the Greek Ministry of Education did not provide a clear time schedule as to when authorization would be granted for the pilot study to be conducted. It was, therefore, decided not to request extended access from the Ministry of education with the researcher accepting and meeting any access opportunity offered from head-teachers, teachers and parents. This way, the selection of the schools and the classrooms for the conduction of the pilot study was based upon a pre-existing relationship with the head teachers and teachers in the central area of Greece.

In addition to gaining the approval of the Minister of Education informed consent was also sought from the stakeholders (head-teachers, teachers and parents) as well as the study sample about the conduction of the pilot study and its purposes. As Homan (2001) stated "the principle of informed consent is a standard feature of ethical procedure in social research" (p.330). With this in mind, it was intended to ensure that children and their parents were aware of the former taking part in this pilot phase. They were informed about the aims of the research and that children's participation was voluntary.

A questionnaire was individually given to these students and then each year group participated in a group discussion. Although there was a question in the questionnaire asking for explanations students were asked to explain them further in the group-discussions/interviews. In total, there were 41 students recruited from three different age groups. From these 41 students, 13, 16 and 12 were students from year four (primary education), year 9 (secondary education) and year 11 (secondary education) respectively.

3.6.1 Interview related emergent issues

It was found that the research instrument was able to generate considerable and relevant data that served the purposes of the study. Overall, the majority of students did choose the option that they had been expected to choose on the basis of the literature. However, they rarely mentioned analogies in their written explanations, whereas, they did so more often during the interviews. Therefore the initial strategy of conducting informal conversational interviews without having a predetermined list of questions was transformed to the conduction of semi-structured interviews in which the questions and their sequence was predetermined in advance. This way, instead of simply asking the question "what makes you think that?", there were some more questions developed in order to be used during the group interviews to scaffold students' explanations of their thinking and prompt reference to analogies in their answers. The questions that were used during the interviews are:

1) What makes you think that?

2) Why do you think your prediction is the correct one?

3) Why do you think is A the correct prediction and not B or C?

4) Is there anything you have observed in your life and that helped you to choose your answer?

6) Why did that help you?

5) Is there any example from your daily experience/life that looks to be similar with this situation?

6) Could you think of a similar situation that you can explain more easily than this one?

These questions were asked to the students during the group interviews/discussions and they were used in order to increase the depth and richness of the responses, enhancing this way, as Oppenheim (1992) argued, the validity of the interviews.

3.6.2 Emergent issues related with the research instrument

The basic problem with the questionnaire was the ambiguity of the novel situation 6 (boat with a fan). Many of the students, being highly observant, did notice that the flag and the sail in the picture are waving. This shows that there is wind blowing from the right to the left if the curve of the sail is carefully observed whereas, there is also wind blowing to the opposite direction if someone takes into consideration the position of the flag (when, in both cases, the fan is switched off). This could be avoided by making some changes to the picture. However, this was not the only problem with this question. It was therefore decided to remove the situation from the questionnaire.

Based on discussions with the teachers who claimed that using bombs questions would appeal more to boys and discussions in the advisory group about the masculine type of such questions, several changes were made concerning 3 questions. The sequence of the options changed as well so there was no any confusion between the bombs (which actually became lights in order to avoid the masculinity of questions) and the letter of the options provided. The improved version of these situations is presented in the appendix G.

3.6.3 The modified research questions

The initial research questions mentioned in subsection 3.3 of this present study had emerged from the literature review and they had been relatively broad in terms of their focus:

a) How students make predictions of novel situations?
b) How does the use of analogies affect their predictions?

The pilot study showed that whilst students employed analogies in their thinking in order to provide a prediction, they did not mention any analogies in their written explanations. In other words, they did not do it explicitly. It also showed that although students generated analogies during the group interviews, in some cases they did provide analogies but only when they were asked to do so.

It was therefore decided that the research questions could be refined in order to take into consideration the preliminary findings from the pilot study. The refinement process resulted in the formulation of the following more specific research questions:

a) How do students of different ages make predictions about novel situations?
b) To what extent do students spontaneously generate analogies in order to make their predictions?
c) To what extent do students of different ages draw upon similar analogies?
d) Is there any evidence of basic mental constructs, i.e. p-prims, in the analogies students generate when they try to make predictions about novel situations?

In addition to helping in research questions refinement, the pilot study was important for the data analysis as well. It helped in the refinement and further development of the nature of the data analysis. The strategy for the data analysis is presented in the last subsection of the present chapter.

3.7 Ethical issues

As mentioned previously, the selection of the schools and the classrooms was based on a pre-existing relationship with the stakeholders in the geographical region of central Greece. Following the procedures proposed by the Greek Ministry of Education, the request for extended access was given for both primary and secondary education.

After that, the stakeholders as well as the study sample were informed about the conduction of the present research and its purposes. In order to ensure that parents were aware of the students taking part in the research and that there were audio tape recording techniques involved, a letter was written in collaboration with the teacher of each classroom and was delivered to the parents. Parental consent was obtained and moreover, prior to the administration of the questionnaires and the conduction of the interviews, students were informed that they could withdraw at any point.

3.7.1. Anonymity

Given the ethical obligation from the part of the researcher to protect the anonymity of the teachers, students and their institutions (Frankfort-Nachmias & Nachmias, 1992) it was decided not to provide any details of the schools which participated in this study and use codes instead of students' names in quotes from their answers.

3.7.2. Ethical issues emerged from the pilot study

In the pilot study, it was found that teacher's comments had significant impact on the students' predictions, explanations (written questionnaire) even on the analogies they came up with in the group interviews. While attempting to help their students, teachers were issuing directions and guidance which led them to choose the answers that the former considered as being the scientifically correct.

Therefore, in terms of interviewing the students it was decided, after discussions with the head-teachers and the class teachers, to carry these out as in the pilot study, but with the teachers remaining in a side room off the classroom so that group interviews were effectively being conducted under their direct supervision yet out of ear shoot.

3.8 Data analysis

After the interviews were transcribed, students' predictions were compared across the three different age groups. A modified version of Clement's (1988) framework was used to identify how the analogies were generated. In brief, the framework identifies three resources or processes for producing analogies: a) generation via a formal principle (recognition of the original problem as an example of a principle or an equation and generation of the analogous situation B as another example of that principle), b) generation via a Transformation (an analogous case is produced by modifying some features of the original case), c) generation via an association (participant is reminded of an analogous situation in memory which might differ in many aspects from the original situation but it can still have important similar features).

Clement's methods for generating an analogy derived from experts' thinking of novel problems. It is plausible to assume that the students of the present study would not be able to think and make predictions the way that experts do. This assumption could be supported from Chi et al.'s (1981) findings according to which experts and students do not have the same categorization and reasoning ability that scientist have. Data from the pilot study also supported this claim (the main study showed this too). Students' explanations of their predictions were not so sophisticated in comparison to experts' thought of problems in Clement's study (1988).

Therefore, Clement's framework was modified in order to be used for the analogies that students generated to explain their predictions. Examples of each type and any differences in relation to Clements' (1988) framework are discussed below.

1. Generation from a Formal Principle. This type of analogy generation method is used in the same sense that Clement suggested. This method describes analogy generation derived from a formal principle (for instance, the principle of conservation of mass) or a simple equation. Analogies are generated by the recognition of the novel situation as being an example of a simple equation or a formal principle and subsequently, the analogous situation is generated as a second example. Consider the following example from one of the students who was trying to make a prediction for the weight and gravity question (novel situation 4, elephant vs. ant):

> *It is like dropping two stones of different mass from the same height. Both fall at the same acceleration in absence of air resistance. According to the equation of time for a free falling object, balls hit the ground at the same time. Therefore, in this situation both bulbs light up at the same time.*

$$t = \sqrt{\frac{2d}{g}}$$ *d is the same, g is the same for both movements, therefore, t will be the same as well.*

(9th grade student)

In the figure below (Figure 3.5.12) Clements' (1988) schematization is used as a representation of the analogy generation via a formal principle in the above example:

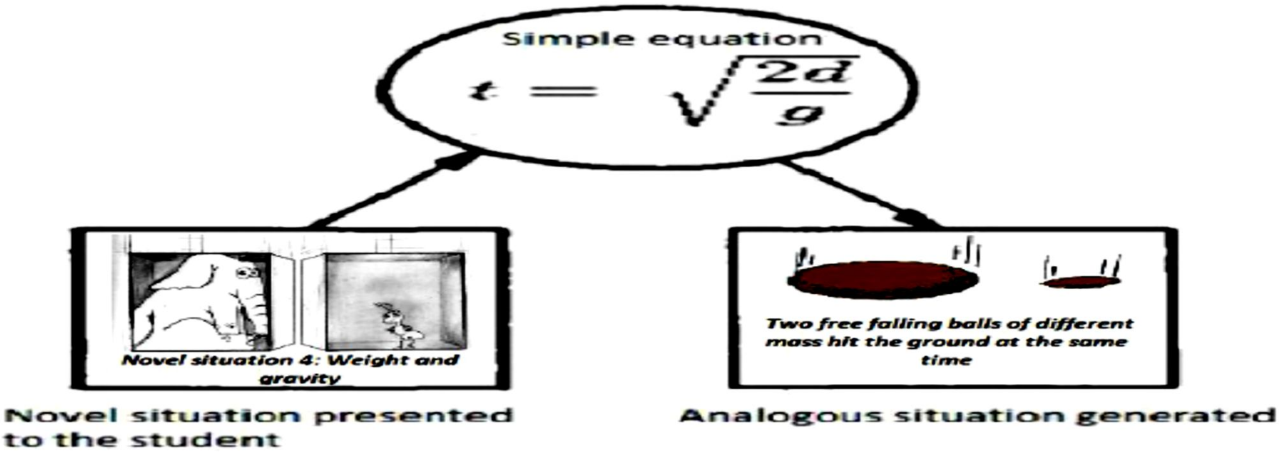


Figure 3.5.12 Example of an analogy generated from a formal principle.

2. Generation via a transformation. According to this method, an analogy is generated by modifying the novel situation presented. In these instances, students change very few characteristics of the original problem/question generating this way the analogous situation. Also, in this case, there is not any mention of equations or formal principles. The following is an example of an analogy generated by a student who was trying to explain the same situation like the one considered in the previous example (novel situation 4, weight and gravity).

> *The light bulb that is underneath the elephant lights up first… It is obvious! It is like dropping simultaneously from the same height a bee and a rhino. I bet that a rhino falls much more rapidly than a bee.*

(7th grade student)

It could be assumed that this type of analogy generation occurs when the student focuses on an element of the novel situation and then makes a transformation of this element generating this way the analogy. In the example cited above, it seems that the student focused on the difference of mass between the elephant and ant. The analogy was generated by simply changing this element. The generation process of this analogy is represented in the Figure 3.5.13.

Students in the present study were neither expected to change many elements of the original problem (novel situation), nor to generate first an analogy by changing some of the internal representations of the original situation and then modifying this analogy to produce a more valid one, in order to make a prediction and explain it, a process that Clement (1988) named as a "imagined, continuous transformation" (p. 575). This is because it is difficult for students to generate analogies via transformation like those provided in Clements' study as examples of this generation method. It has already been discussed that students could not think like experts do and therefore it is reasonable to assume that they might not be able to make predictions by producing extreme cases of the given novel situations or by continuously generating analogies until they reach to a valid explanation of their prediction (for more details see, chapter 5; subsection 5.2.2.1). Therefore, the aforementioned method for generating analogies is used to classify students' self-generated analogies produced by modifying very few elements of the novel situations presented to them (Figure 3.5.13).

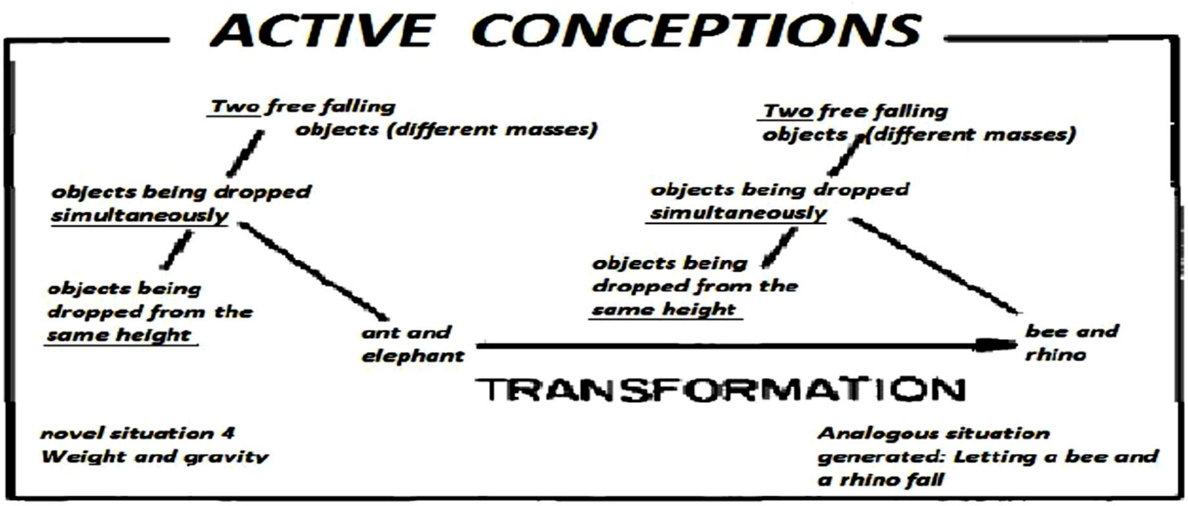


Figure 3.5.13 Example of an analogy generation based on transformation

3. Generation via an Association. A student generating an analogy via an association is reminded of an analogous situation in memory that might be different in many ways from the original novel situation presented to them. However, the analogous situation they have been reminded of still has

important features in common with the novel situation and can be used to make a prediction for the latter. In contrast to the previous generation method, there are not any modifications in the elements of the novel situation presented to the student, rather there is an entirely different analogous situation generated that has something in common with the original problem. Consider the following example of a 6th grade student who was trying to explain the prediction been made for the novel situation in which two identical candles, one of them being lit, are balancing on a beam (novel situation 1, burning a candle) :

> *Bulb A will be switched on… Mass decreases as the candle burns and thus the beam turns to the side of bulb A… It is like having a wet sponge and a dry one trying to balance them on a beam. The only way to make it is to squeeze and twist the wet one.*
>
> *(6th grade student)*

In this example, the student compared the burning candle novel situation with a situation of wet and a dry sponge. The two situations are fundamentally different, but there is a concept in both situations that seems to play a role in the activation process of the analogy. The student focused on the concept of something being dripped off in both situations and this concept allows him to make the association, generate the analogy and think that as long there is something being driven off there should be a decrease in mass. Figure 3.5.14 represents the activation of the analogy in this particular case.

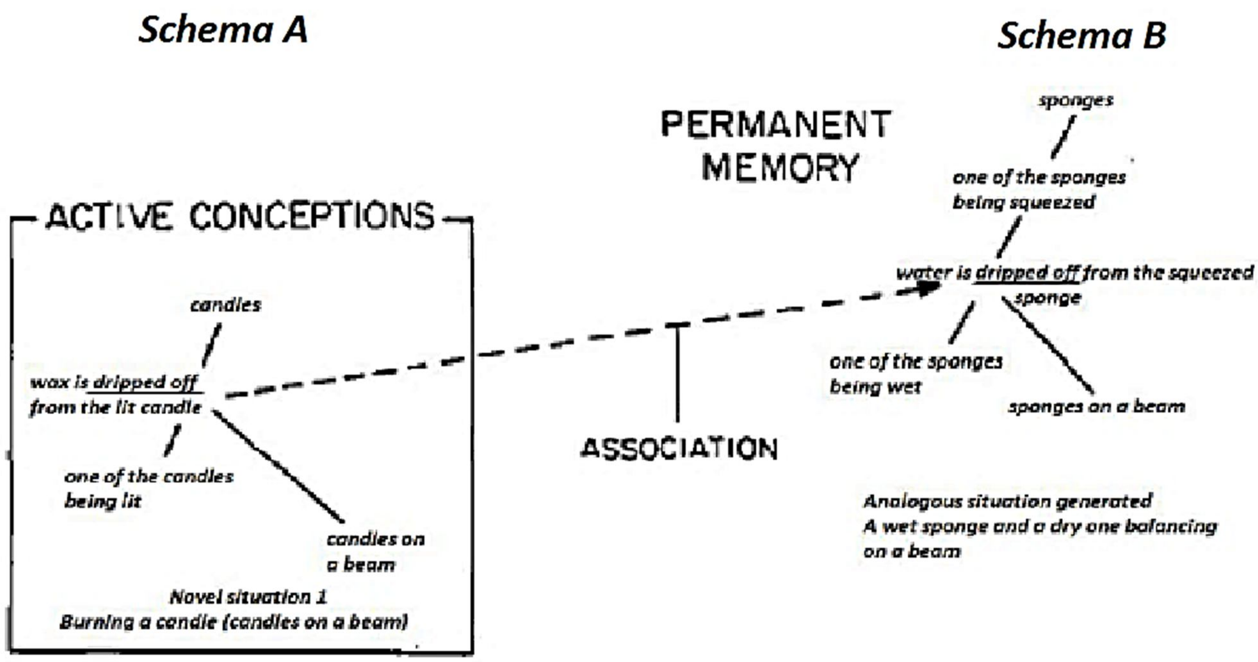


Figure 3.5.14 An example of an analogous situation being generated by association

Associative analogies do differ from those produced via a transformation because they are entirely different situations sharing very few characteristics. In Clements' words, associative analogies "tend to be more distant from the original situation" (1988, p. 577). Thus, in sharp contrast to the construction of an analogy via a transformation of a schema A in temporary memory (the second type of analogy generation method discussed above), the fact that the generated analogous situation differs in many ways from the novel situation would suggest that there is an established schema B stored in permanent memory (as shown in the figure) which is activated by association.

Apart from analysing the analogies in terms of the generation method they were also classified in three categories according to the way that analogies were generated. Explanations that involved analogies being generated without any provocation were classified as Direct Spontaneous Explanations (DSE). For example, analogies that were mentioned in the written explanation of the prediction that students provided in the open-ended question of the questionnaire were classified as being such. This is because there was not any kind of lead from the part of the researchers to the students so as for the latter to provide an analogy as part of their predictions' explanation. DSE were also found in the transcribed interviews. Consider the following example taken from the transcription of a group discussion about the weight and gravity novel situation:

> Interviewer: "*What do you think about this situation? Will the bulbs be switched on at the same time or will one of them be first?*
>
> 4th grade student: *The light bulb that is underneath the elephant lights up first and that is because heavy objects fall faster. The elephant is much heavier than the ant and that makes the elephant to fall faster... A piece of metal falls faster than a tissue..."*

In this case, the student provided the analogy without being provoked by the interviewer. The analogy was generated as the student was trying to make a prediction about the novel situation presented to him.

Analogies that were generated as students were asked by the interviewer to elaborate more on their explanation constitute another category, that of Indirect Spontaneous Explanations (ISE). ISE included analogies that were generated during the interview settings. The role of the interviewer in this case was to ask students questions that might help them to explain their predictions. What follows is a typical example of this type of explanation. The analogy was generated by a 6th grade student while trying to explain the prediction made about the burning a candle novel situation.

Interviewer: "*What do you think of this situation? Will one of the bulbs be switched on?*

6th grade student: *Hmmmmmmm... Let me think about it...Yes! One of them is going to be switched on...*

Interviewer: *Could you please tell me which one of the two?*

6th grade student: *The A one.*

Interviewer: *Great! And could you please explain to your classmates what makes you think that?*

6th grade student: *I have observed that wood becomes lighter when it burns, I have seen it happening with the firewood my father places into the fireplace. I can see that... Burning things become lighter! So, the burning candle becomes lighter causing the other one to press the button and… turn the bulb on!"*

The last category is Prompted Indirect Explanations (PIE). In sharp contrast with the previous type of explanations, students were asked straightforward by the interviewer to provide an analogous case with the novel situation already presented to them. Consider the following example of an explanation provided by a 4th grade student. In the explanation the student involved an analogy when attempting to explain further the prediction made for the novel situation 3 (objects falling in holes dug into the Earth).

Interviewer*: "What do you think? Where will this person stop?*

4th grade student: *Hmmmmmm... I am not sure... Is the tunnel a circular one?*

Interviewer*: Not at all! It is a tunnel dug straight down with nothing being in it. If it was to look from the one side you could see the other side and the net. Did that help you? What do you think now?*

4th grade student*: If the tunnel is a straight down one and there is not any obstacle in it then definitely the person will stop into the net.*

Interviewer*: That is a great idea! Could you please explain to the others (in the group) what makes you think that?*

4th grade student*: Hmmmmmmm... I do not know... Maybe because there is not something to stop the person.*

Interviewer*: Right... There is nothing to stop him, but why do you think that your prediction is the correct one? Why is C the correct answer and not B or A?*

4th grade student*: C is the correct answer! As I said nothing stops him from entering into the net.*

Interviewer*: All right! Is there anything you have observed in your life and that helped you to choose your answer?*

4th grade student*: Hmm.......It is like putting a small ball in a tube! It will fall downwards towards the other side.*

Interviewer*: That is a great! But how did this help you to answer this question?*

4th grade student*: It is the same! Isn't it? The person is like the ball being left to fall in a tube! The ball falls downwards towards the other side of the tube and if I don't catch it falls to the ground! The same happens with the person who jumped into the hole! There is the net there to catch him!"*

As the transcription clearly shows, the interviewer asked the student to provide an example deriving from daily experiences that could help the student to justify the prediction made. Therefore, the analogies involved in this type of explanations (PIE) were an act of prompt.

3.8.1 Data analysis Validation technique

Although, it is impossible to fully confirm findings from a mixed method study as it involves qualitative approaches (Cohen et al., 2007), it was attempted to reach a high level of external validity. Several authors have argued for the use of triangulation methods to improve the external validity of studies (Cohen & Manion, 1982; Patton, 1987; Yin 2003). As Ritchie and Lewis (2003) noted, triangulation refers not only to the use of two or more methods of data collection in the study but it is also related to the data analysis. Aiming at confirming as well as improving the clarity and precision of the research findings, there are two methods of triangulation used.

The first method refers to the comparison of data generated by different qualitative methods, a technique known as triangulation of sources (Denzin, 1978). The present study adopts this technique triangulating on the basis of data in so far as the data used in the study are collected from responses in the questionnaires and interviews. The aim was not only to check the validity of the collected data but also to give the ability to the researcher to corroborate the same fact or perception using different primary source material.

The second method is related to the validation of findings. As Patton (2002) stated “It is in data analysis that the strategy of triangulation really pays off…” (p. 556). In order to contribute to the accuracy of the findings, triangulation through multiple analysis method (Denzin, 1978) was used in this present research. This method refers to the use of different analysts to check the way the data were collected and interpreted. To obtain criteria for the validity of the data collection, their classification and interpretation, two postgraduate students of a science education department and one more person (outside the area of science education specialism) were recruited. They were given the transcription of the interviews and questionnaire scripts, the categories discussed above along with the examples (section 3.8, data analysis) and they were asked to code students’ responses. Where disagreement about the coding existed it was resolved through discussion among the coders and the researcher.

Chapter Four

Data analysis

4.1 Introduction

This section presents the analysis of data collected from the ten classes that took part in the present study.

Whilst the data collected from the multiple choice questions could have been easily presented and findings from these could be effectively reported by using statistical methods (Miles & Huberman, 1994), there is not a single approach for presenting data and reporting findings from the responses provided in the open ended questions and during the group discussions and with such a large volume of data collected, the researcher had to be selective about what data should be presented in the analysis. Therefore, at this point and even before starting to analyse the data what should be resolved is the issue of which data are to be presented within the thesis.

There are many different approaches to the issue of presenting qualitative data and findings resulting from them. Whilst several authors have argued on the importance of presenting relatively large amounts of direct quotes and recorded data (e.g., Rudduck, 1984; Ball, 1990; Bowe, Ball & Gold, 1992), trying to present and retell everything is not likely to be very useful to the process of analysis. Indeed, such an approach generates what Miles and Huberman (1984) refer to as “word overload” (p.56) that can result into overwhelming the reader with an excessive amount of information that does not facilitate understanding of data analysis.

Miles and Huberman (1984) argued that underpinning everything using original data in a text implies that more words will have to be worked out without this necessarily meaning that analysis will be more advanced because these words might not be meaningful for the purposes of a study.

Similarly, Wolcott (1990) has argued that the major task for a researcher after collecting the data is to “get rid of it” (p.13) in the sense that data should be used selectively in order to exemplify and illustrate the story the researcher intents to tell. White, Woodfield and Ritchie (2003), following this suggestion, argued that there is certainly a choice to be made about not including all of the data in a study otherwise, by trying to re-tell everything, writers end up showing everything and yet explaining nothing.

The choices that qualitative researchers make regarding what data to include, and what to exclude, should fit the research methods and more importantly the purposes of the study. Findings of a study are not based solely on the data itself, regardless of how obsessively they might be examined, as there needs to be a "constant interplay between the ideas we work with and the detail of form and content in the data themselves" (Coffey & Atkinson, 1996, p.155).

Reid (1978) criticising the inclusion of too much data material in studies argued that:

> *Apart from supporting the book and paper industry, it is a curious habit (...) it also begs the question as to why the author should have bothered to present an interpretation at all if it is not superior to another, or if the whole job can be done by the reader (...) In any case, research has never been only about the collection of data and it is always about interpretation, presentation and communication.* (p. 29)

However, this should not be perceived as suggesting a need to avoid presenting any original data but rather as suggesting the need to maintain a balance between the original data and their interpretation. A readable and at the same time interesting report "provides sufficient description to allow the reader to understand the basis for an interpretation, and a sufficient interpretation to allow the reader to understand the description" (Patton, 2002, p.503-504).

The approach used in this thesis, following Morse, Kuzel and Swanson (2001), was to present and report some aspects of the data collected which can demonstrate the basis on which interpretations have been made and findings have derived from. The aim is to provide some of the available evidence in order to support the interpretation of the data being presented to the reader.

In this way each type of analogy generated by the students, the ideas that were expressed as the students were trying to explain their predictions and examples of the categories in which the analogies were classified are presented using appropriate verbatim quotes from the written responses in the questionnaires and excerpts from the transcribed interviews. These verbatim quotations have been selected either to illustrate a specific point or as exemplars of a particular type of analogy, category or idea which emerged widely within the study.

What follows is the presentation of the analysis of the data collected for the first novel situation (weight and gravity situation). The analysis of this situation was done in three parts. The first part refers to the analysis of the data collected via the questionnaire administered to the students whereas the second one presents the analysis of the data gathered through the group interviews. The last part offers a synthesis of the findings from the first and the second stage.

In the first part, SPSS, as being the most commonly used statistical data analysis software in educational research (Muijs, 2004), was chosen to analyse the data from the multiple choice questions. The same approach was used for the analysis of students' explanations of their predictions in terms of whether students used analogies. In this sense, students responses were transformed into numbers in order to process the data more economically as well as to make less ambiguous their presentation and analysis (Miles & Huberman, 1994).

The second part of the analysis of each situation provides descriptions and analysis about what happened when the students engaged in the group discussion. Although students' predictions about the situations were recorded in the closed-choice questions of the questionnaire and were therefore expected to remain unchanged during the group discussion, what was analysed in this part of the study was the way that students explained the predictions they made.

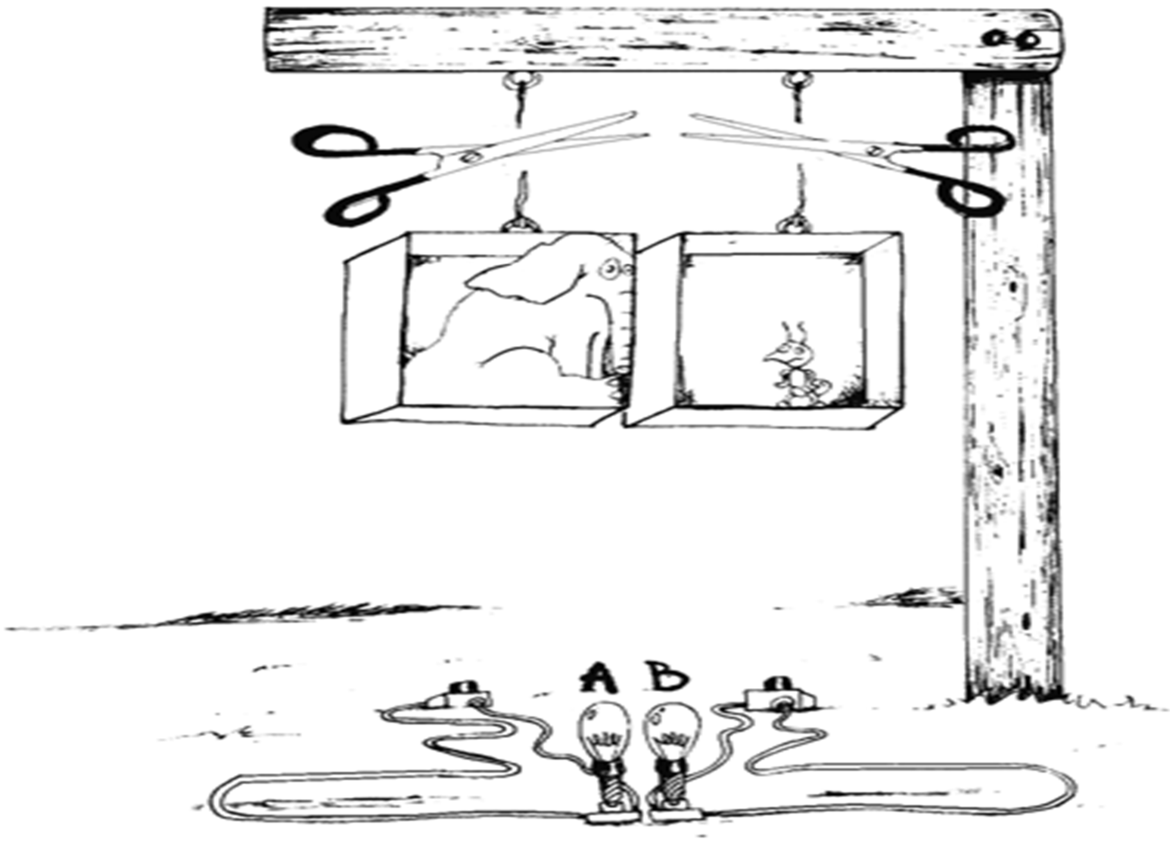
The data from the group interviews were analysed in terms of the responses students gave to explain what led them to make their prediction. The analysis focused on whether students used analogies in their explanations. However, analogies were not only identified in students' responses during the group discussion/interview but in many cases students involved analogies in the explanations they wrote in the questionnaire. The framework for the analysis of these responses could be seen in the previously described part (section 3.8). In order to synthesize the data from these two sources of data (group discussions and interviews) responses were transformed into frequencies as well. The synthesis is presented in the third part.

The third part of this first situation (weight and gravity novel situation) analysis links the findings from the first and the second part presenting an overview of the analysis. Again here SPSS software was used to present and analyse the data deriving from the previous two parts.

It should be added here that the analysis of the following novel situation exemplifies the analysis of all the other situations. Being divided into three parts the following analysis provides clear and rich details on how the data collected from the three different sources namely, the multiple choice questions, the written responses in the questionnaire and the responses given during the interviews were used for triangulation purposes.

In order to avoid being repetitious, the analysis of all the other five novel situations is limited to one subsection which synthesizes the analysis of the data collected through the three different approaches previously described.

4.2 Analysis of novel situation 1: Weight and gravity.



If the ropes shown in the figure are cut at the same time, will the bulbs be switched on at the same time or will one of them be first?

A) Both at the same time *B) Bulb A first* *C) Bulb B first*

4.2.1 Analysis of the questionnaire data

When the questionnaire was administered to the students, there were some instructions given about its completion. For this question, it was stressed that there was no wind blowing that could move the boxes as they are falling. Moreover, students were told that air resistance (air and/or wind) must not be taken into consideration in their prediction.

The analysis of this questionnaire data, as it occurred with each of the novel situations, was carried out in terms of the predictions made and the explanations provided about them. However, in many cases, responses in the open ended question were used to help inform and/or understand the prediction students chose. Triangulating across both these two sources of data, the open-ended and multiple choice questions, aimed to maximise the validity of data.

Although, according to the findings, both sources supported each other, there were a few cases in which students had chosen an option from those listed in the closed-choice question, but in their written explanations it became apparent that what they were explaining was fundamentally different to the prediction option they had selected. In these cases, the prediction that students explained in the open-ended question was the one considered as representing what was their actual prediction of the situation.

The results from the closed-choice question about the predictions that students made for the weight and gravity situation (novel situation 1) are presented below (Table 4.2.1).

The row named as expected count in the Table 4.2.1 was calculated using SPSS. For comparing the two variables (students' age and the prediction they made) cross tabulation method was used. The essence of this statistical method is that it provides a table (similar to the one presented here) that shows the number of students in each school grade and the prediction they made.

More importantly, this method can be used to indicate if there is any relationship between the two variables (a method known as bivariate analysis) (Cohen et al., 2000). In this particular case (weight and gravity situation) this method is used in order to see if age is a factor that affects students' ability to make predictions about novel situations.

The same method was used throughout the other five situations so as to see if there is any relationship between the age of the students and the prediction they made. To prevent too much repetition, the process of how cross tabulation method works is only presented in the first novel situation analysed below.

As Cohen, Manion and Morrison (2007) illustrate, the expected count in the cross tabulation statistical analysis calculates the number of cases expected to fall in each case if there was no relationship between the two variables examined. This is done by knowing the percentage of one variable (in this case, either the number of students belonging in one age group or the number of students that chose a particular prediction) of the whole (the whole study sample or the total number of responses) and subsequently by calculating the number of the cases that would be expected to be found in each group. In case when no relationship is being found, it would be expected that the cases would be represented in each group in the same proportion as it is found in the study sample.

To make the previously described process more clear, an example of the first expected count value of Table 4.2.1 is provided (value 4, 7). Assuming that the age of students is not related to the predictions they made, the number of students of a particular age group that would be expected to choose a particular option can be calculated (students' age is considered to be the independent variable and students' prediction the dependent one). There are 37 students aged ten years old (4^{th} grade) out of the 166 students participating in this study. This means that 10-year-old students make up approximately 22.3% of the study sample (37/166). Given this percentage, the number of 10-year-old students that would be expected to select A prediction option (bulbs will light up at the same time), if there is not any relationship between the variables of age and predictions made, can be calculated. In the whole study sample, there are 20 students that chose option A. Therefore it is expected that 22.3 % of them would be at the age of ten and this means that $(0.223 \times 20) \approx 4.5$ 10-year-old students would be expected to make the prediction that bulbs will light up at the same time. This is exactly the way that expected values are calculated.

Table 4.2.1 shows how many students from each age group chose either A, B and C options provided in the closed-choice question. Comparing the expected with the actual values it can be seen that students in each age group chose options A, B and C at almost exactly the same level it would be expected if the two variables (age and prediction option chosen) were not related. What this shows is that there is a low probability of students' age being related with the prediction they made.

Whilst it can be seen that there are some slight differences between students aged 10, 12, 13, 15 and 17 years in how they respond to this closed-choice question what is not tested is the possibility of the differences to be a result of chance factors or errors in sampling (Schutt, 2006). However, it is plausible to assume that this is not the case, as there were almost equal numbers of students being recruited from each age group. Two classes for each age group participated in the study sample with the number of students being approximately from 16 to 19.

A Chi square test was not used with the data to test whether the observed differences were due to sampling errors in Table 4.2.1 as many are less than one and moreover, more than 20 % of the expected values are less than five and as Muijs (2004) makes clear, such low values make the chi square test problematic.

With the chi-square statistic test being ineffective and inadequate, an alternative statistic test was calculated to overcome this problem. As Cohen and Holliday (1996) suggest, the Fisher exact test can be used when a chi-square test cannot be applied. This test was used in all the other situations in which the chi square test was ineffective. Although, the chi square test and the expected values were calculated for the analysis of the data collected in all the situations these values are not presented because they were not employed to show if there are any difference across the ages. The expected values were calculated to see if there were values that constitute these tests problematic. Instead, the values appeared in order to identify any statistical significant differences were those of the Fisher exact test. Nevertheless, there are some cases (for example, the analysis of some novel situations in terms of whether students used an analogy in their explanations) in which the previously described problem did not exist. In these cases, chi-square statistic tests were used and a reference is made to these values.

predictions in novel situation 1 (weight and gravity)		Students' age 10	12	13	15	17	Total
A) Bulbs will light up at the same time (the correct, scientific one)		**0**	**2**	**3**	**8**	**7**	**20**
	Expected Count	*4,5*	*3,7*	*3,5*	*4,2*	*4,1*	*20*
B) Bulb A will be first		**36**	**28**	**26**	**27**	**27**	**144**
	Expected Count	*32,1*	*26,9*	*25,2*	*30,4*	*29,5*	*144*
C) Bulb B will be first		**1**	**1**	**0**	**0**	**0**	**2**
	Expected Count	*0,4*	*0,4*	*0,3*	*0,4*	*0,4*	*2*
	Total number of students in each age group	37	31	29	35	34	166

Table 4.2.1 Students' predictions across the age group of the study sample for novel situation 1 (weight and gravity)

As can be seen, a minority of students across all the age groups were able to provide the correct and scientific prediction. In accordance to the previous claim concerning the agreement of the expected and the actual values in the Table 4.2.1, there was not a significant correlation between age and the prediction made (Fisher's exact test= 15.608, p= 0.062). Nevertheless, grouping together and comparing the responses given from students in primary education (aged 10 and 12 years) with those given from students in secondary education (aged 13, 15 and 17 years), a significant difference was found (Fisher's exact test=13.694, p=0.028). The effect size is moderate according to Cohen's (1988) guidelines (Cramer's V=0.206). There were larger proportions of students in secondary education choosing the scientific prediction rather than in the first group. The higher achievement of students in secondary school in choosing the correct option could be related to the introduction of the concept of gravity in Year 6 of secondary education (students at this stage are approximately 14 years old). The analysis of the explanation responses could show what led these students to make the correct prediction (these are examined below).

It is apparent that option B (the bulb that is underneath the box with the elephant included will light up first) was the most popular response. Although Table 4.2.1 summarises the outcomes of students' choices in the multiple choice question, the previously described analysis does not convey why students made these predictions and the reasons that made them believe that the predictions they made were the correct ones. The analysis of the open ended questions found in the questionnaire illustrates the way that students explain the predictions they made in the closed-choice questions. The explanations were analysed in terms of an analogy being, or not being, involved in students' written responses. The analysis of these data is presented in the following paragraphs.

From the analysis of the open ended questions, it was found that students in all grades generated analogies in order to make a prediction. What emerged was the involvement of analogies in students' explanations of predictions even in the case of predictions compatible with the scientific view. Table 4.2.2 below shows in how many cases students generated an analogy so as to explain what led them to make a prediction along with the prediction option they chose for this particular situation (weight and gravity).

Irrespective of the option chosen, just over half of the students (87 out of the 166) made their prediction on the basis of analogies. These findings would suggest that a common way for making predictions about this particular situation is based on the use of analogies. Also, it can be seen that almost half of the students' written responses in each age group involved an analogy in order to explain their prediction. It is worth noting, despite there being no association between age and the use of analogies in the explanations students provided (Fisher's exact test=2.909, p=0.575), there was a slight, nonstatistically significant difference in the use of analogies by students in Year 6 (students 12 years old) and Year 9 (students 15 years old) as in these two groups, the percentages were higher (20 out of the 35 students in the former age group and 19 out of the 31 in the latter). This suggests that irrespective of students' age, a common way for making a prediction for this situation was on the basis of an analogy.

This analysis does not convey how these analogies were generated and, moreover, the type of analogy used in terms of the framework described in the previous chapter. As it is discussed earlier in this chapter, extracts from the questionnaire responses are essential in presenting original data which in turn are useful in constructing meaning from them. In this particular case, examples of students' written responses can provide an insight into some aspects of students' explanations as well as their method, the type of the analogies generated as well as the ideas involved. In what follows, exemplars of students' responses of all ages are presented for the two predictions (A and B options) in which there were analogies involved.

With option B (the bulb that is located underneath the box containing the elephant) being the most common prediction made across all ages the majority of the analogies were generated by students in their attempt to explain why B is the correct one. It can be seen in Table 4.2.2 that almost one out of two students who believed that B is the right prediction used an analogy in their explanations. This suggests that generation and use of analogies played a significant role in the process of making a prediction about this particular situation (novel situation 2).

Students from across the five grades who chose option B self-generated analogies. As it can be seen from the examples provided, all of these analogies were of similar type. It should be added here that, as it is the case for every analysis of the situations examined in the present study, students were given code numbers. Codes started with S (student) and it was followed by a number indicating the age of the students and at the end with another number indicating which case is represented. So, for example, S15.3 would indicate that this student aged 15 and that they are recorded as student number in this study. Also, where a reference is made to a number of students, there is letter n in a parentheses equated to that number (n=…).

predictions in novel situation 1 (weight and gravity)			Students' age 10	12	13	15	17	Total
A) Bulbs will light up at the same time (the correct, scientific one)	*involvement of analogy in the written explanation of predictions*	student DID self-generate an analogy	***0***	***0***	***3***	***4***	***4***	***11***
		student DID NOT self-generate an analogy	***0***	***2***	***0***	***4***	***3***	***9***
	Total		***0***	***2***	***3***	***8***	***7***	***20***
B) Bulb A will be first	*involvement of analogy in the written explanation of predictions*	student DID self-generate an analogy	***17***	***19***	***12***	***16***	***12***	***76***
		student DID NOT self-generate an analogy	***19***	***9***	***14***	***11***	***15***	***68***
	Total		***36***	***28***	***26***	***27***	***27***	***144***
C) Bulb B will be first	*involvement of analogy in the written explanation of predictions*	student DID NOT self-generate an analogy	***1***	***1***	***0***	***0***	***0***	***2***
	Total		***1***	***1***	***0***	***0***	***0***	***2***
Total	*involvement of analogy in the written explanation of predictions*	student DID self-generate an analogy	***17***	***19***	***15***	***20***	***16***	***87***
		student DID NOT self-generate an analogy	***20***	***12***	***14***	***15***	***18***	***79***
	Total number of students in each age group		***37***	***31***	***29***	***35***	***34***	***166***

Table 4.2.2 Predictions made and use of analogies in explanations provided from students of all grades.

The four examples of students' responses below illustrate explanations in which students involved an analogy in an attempt to justify their prediction according to which the bulb that is placed underneath the box with the elephant in it lights up first.

> *What led me is that the elephant will drop faster than the ant. It is like letting an olive and a leaf, the olive falls faster.*
>
> (S10.1)
>
> *Because the elephant is heavier than the bug, thus when you cut simultaneously both of the ropes the elephant falls first and the bulb A will switch on first. I have seen in everyday life a whole book falling faster than one single page of a book.*
>
> (S12.2)
>
> *In my opinion bulb A will switch on first because the left box has greater weight and greater gravity than the right and therefore, the one that includes greater mass will fall down first. It is like the example in which we drop from the top of a roof a dumbbell and a feather, the dumbbell always falls faster. This happens because the weight is greater.*
>
> (S15.3)
>
> *The box with the elephant in it will fall faster, since the gravitational forces being exerted from the earth will be greater. It is like the example in which a ball falls faster on the ground than a feather. This is the case even if there is air resistance which will create a different but in any case greater resultant force on the object* [meaning the heavier one].
>
> (S17.4)

It can be seen from the excerpts above some students (for example, S15.3 and S17.4) articulately responded to the question about what made them think that the prediction they made was the correct one. Other students (like S10.1) although they did not express their responses fluently, did involve an analogy in their explanations and it can be easily seen how the analogy was generated and how it led students to choose option B.

Although the above responses differ in terms of their articulacy they do typify the justifications used by the majority of students in explaining their predictions. More importantly, all of these responses have two similar characteristics. The first one is the method by which the analogy itself was generated and the second is related to the ideas upon which the explanations were based.

According to the analysis framework described in the previous chapter, the analogies generated in the four examples above were classified as being generated through transformation. Students changed very few characteristics of the weight and gravity situation generating an analogous case which, according to their responses, helped them to make a prediction. It seems that the students focused on the difference of mass between the animals being placed in the boxes (the elephant and ant).

The students in the above examples generated an analogy by simply changing these two animals with two different objects, keeping at the same time the element of mass difference. For example, S10.1 generated an analogous case of an olive and a leaf being dropped whilst, S15.3 claimed that this situation is very similar to two free falling objects like a dumbbell and a feather.

The majority of students (73/76) who used an analogy to explain the choice of option B focused on the element of mass difference and this is how they generated the analogy. The only difference was that instead of replacing the elephant and the ant with two other objects, some students provided analogous situations in which two other animals were dropped from the same height (for example, a bee and a rhino, a fly and a sheep or a cow) or, in some cases, they even suggested two people of different mass (a fat and a thin one as some students wrote) falling from a tree, a roof or into the sea. From these 73 analogies formed via transformation, 12, 17, 10, 15 and 19 were generated from students in Year 11 (aged 17 years), Year 9 (15 years old), Year 7 (12-year-olds), Year 6 (aged six years) and Year 4 (10-years-old) respectively.

Only three analogies involved in explanations provided by students who claimed that option B was the correct one were formed via an association. In this case, these three students from Years 6 and 7, aged 12 and 13 years respectively, claimed that they were led to this option by being reminded of an analogous situation that they remembered that was different in many ways from the elephant and ant situation presented to them. However, the analogy led students to make the same prediction as it is the case for students that involved an analogy generated via transformation. An illustration of the involvement of an analogy generated via transformation is shown with reference to the three responses in which this generation method was detected:

> *I think that bulb A lights up first because the first box that includes an elephant is heavier. As a result this first box will fall faster and therefore bulb A*

will be first. For example, a fat person that weights of about 100 kg is able to jump faster and go higher in comparison with another one that weights 50 kg.

(S13.5)

What led me to this answer is that the elephant is heavier than the ant and thus, gravitational force attracts it faster. Like a cat which would not be able to jump high if its weight was 40 kg because gravity would not allow it.

(S13.6)

Heavier objects fall faster than lighter ones. It is like the balance scale, the object that is heavier goes down whereas the lighter goes upwards.

(S12.7)

These responses show that analogies used differ a lot from those produced via a transformation. They are entirely different situations, albeit students paid attention to the difference of mass between the elephant and the mouse in agreement with the previous analogies generated via transformation. The analogies generated via an association share only one characteristic with the original situation (the difference of mass) but instead of objects being dropped, student S13.5 generated an analogy in which fat persons are not able to jump quickly and at a great height whereas S13.6 thought of a heavy cat not being able to make great jumps. Entirely different is the case of S12.7 student whose analogy seems to be related to a reminded situation of weighting two objects of different mass on a balance scale.

There was an explanation provided by a 17-year-old student in which the analogy generation derived from a formal principle. The student involved in their explanation an analogy generated by the recognition of the weight and gravity situation as being an example of a principle, albeit it was a faulty principle for this situation. Subsequently, the analogous situation is generated as a second example of this principle. The excerpt of this response illustrates this type of generation observed:

Bulb A will switch one first because the elephant's mass is much greater than that of the ant and since the acceleration is proportional to the mass in free fall then the elephant will reach first the ground. This is exactly like a free falling stone and a piece of paper. Acceleration being proportional to mass shows us why the stone hits the ground first.

(S17.8)

Regardless of the generation method, a similarity that emerges from students' responses is the consistent belief that heavy objects fall faster than lighter ones a finding also reported by several researchers in studies with students in similar ages to these of the present research (Selman, Krupa, Stone & Jacquette, 1982; Osborne, 1984; Driver et al., 1985).

Nevertheless, this idea was not identified only in students' explanations in which there was an analogy involved. The idea of heavier objects falling faster than lighter ones appeared to be widespread among the whole study sample from 10-year-olds to students in Year 11 (aged 17 years). According to the data, 116 out of the 144 students who chose option B (approximately 81% of students who predicted that B bulb lights up first) expressed in their written explanations the idea of heavier objects falling faster. Consider the following two students' responses which are based on the idea that heavier means faster and there is no use of an analogy.

> *Because always this happens. Anything that is heavier falls faster. In this case an elephant is much heavier than a bug* [what is meant is the ant].
>
> (S13.9)
>
> *Bulb A will switch on because the elephant is heavier and thus will fall faster.*
>
> (S17.10)

From all these explanations offered, it is evident that students' conceptions of the free fall of objects are not theoretically grounded but rather they seem to be based upon experiential knowledge. The analogies students used in their reasoning attest to that. It seems to be easier to understand the conception that heavier object fall faster from a p-prim perspective. The conceptions that students expressed appear to be similar with what diSessa (1993) described as the Ohms p-prim. According to him, this p-prim has the same knowledge structure of Ohm's law of resistance: "an agent that is the locus impetus that acts against a resistance to produce some sort of result" (p.126, diSessa, 1993). This is an abstraction from everyday experiences and can be used to understand and make predictions in numerous physical phenomena. As diSessa argued (1983) this p-prim is not only abstracted from examples like "pushing harder in order to make objects move faster" (p. 25), nor it can be used to explain phenomena which have to do with force and related situations. In addition, it can be abstracted from and used in situations "modelling interpersonal relations such as a parent's offering more and more encouragement to counter a child's offering increasing resistance" (p. 25). In this situation, it seems that the focus on the contextual features of the novel situation activated this p-prim which implies that as long as the mass of the elephant is greater/bigger it falls faster.

A common way to make a prediction in this situation was on the basis of the idea that heavy means falling faster. This led the vast majority of students all across the five age groups (144/166) to an incorrect prediction. Also, many of them (76/144) followed a very similar reasoning process by being based upon similar analogies.

Although older students' explanations were similar with those of the younger, it is evident in the above responses (see for example, the responses given by S17.4 and S17.8) that they attempted to synthesise information from everyday experience with formal or even informal instruction. There appears to be a progression in using some scientific knowledge –the application of which was done in an ineffective way- from younger students being merely based on the view that heavy objects fall faster, through the ideas expressed by older students in which the faster fall of heavier objects was related to their weight and/or gravity and to the idea that weight is a force that cause objects to fall. In 23 of the responses given from students in secondary education, like the one of S17.4, there appears to be a link of force with speed and even mass with gravitational force. The two ideas of force being linked with speed and gravity with mass might be what made them think that heavy objects have a bigger acceleration caused by differences in gravity. These findings are in agreement with the outcomes of studies which examined students' ideas about weight and gravity (see for example, Driver et al., 1993).

Despite the fact that the predominant option chosen was B and most of the analogies generated were involved in students' written responses, there were some students that did make the correct prediction by using an analogy in their written explanations. What follows is the examination of this type of predictions.

Only 20 out of the 166 students (12% of the study sample) made the scientifically acceptable prediction. As it is mentioned above, there seems to be a progression from primary to secondary education students' ability to make the correct prediction with those in the first age group not choosing at all option A whereas upper students in Years 6, 7, 9 and 11 made the correct prediction two, three, eight and seven times respectively. Additionally, more than half of them, (11 out of the 20) not only chose the correct option, but also explained by using an analogy what led them to this option (A prediction option). As the figures shows, two of these students were in Year 11, five in Year 9 and three in Year 7 with their age being 17, 15 and 13 ages respectively. Two 12-year-old students who chose option A did not use an analogy in their explanations.

There were two types of generation methods identified in students' explanations of the correct prediction. As it is the case for the explanations students wrote for option B, the vast majority (10/11) of the analogies generated for the prediction that both bulbs will be switched on at the same time were formed via a transformation. For example, S17.11 and S15.2 provided evidence for this generation method when they said:

> *The correct answer is A as both boxes are in a state of free fall. Thus they will reach the ground at the same time. For example, if you take a ball made from iron and a piece of cotton both strike the ground at the same time if you let them fall from the same height. The basic prerequisite is not to take into consideration the factor of weather.*
>
> (S17.11)
>
> *The bulbs will switch on at the same time because the two boxes are identical and the ropes are of the same size. It doesn't matter what each box contains. If we let a small stone and a bigger to fall from the same height they will reach the ground at the same time.*
>
> (S15.12)

These two students used a transformation to generate the analogy by simply focusing on the difference of mass between the elephant and the ant. This way, they generated the analogy by changing the element of the objects being in the state of free fall (a ball and a piece of cotton, two stones and rubbers of different size). Although students were told that air resistance should not be taken into consideration, student S17.11 made a reference to weather conditions which should not be taken into consideration. This reference was made possibly because these students did not pay attention to the instructions given or it might be the case that in order to improve the accuracy of their prediction, albeit they appeared to believe that weather conditions make heavy objects falling faster in everyday life, they explained their prediction by ignoring the factor of weather.

In contrast to the generation of analogies via a transformation, one 17-year-old student generated an analogy on the basis of a formal principle. The response below illustrates the generation method.

> *It is like dropping two stones of different mass from the same height. Both fall at the same acceleration in absence of air resistance. According to the equation of time for a free falling object, balls hit the ground at the same time. Therefore, in this situation both bulbs light up at the same time.*

$$t = \sqrt{\frac{2d}{g}}$$

As d is the same, g is the same for both movements therefore t will be the same as well.

(S17.13)

In this case, S17.3 recognised the weight and gravity situation as being an example of the established equation they provided and then the analogous situation of the two stones of different mass being dropped was generated as a second example of the equation/principle.

In terms of analogy generation method, the findings clearly indicate that irrespective of the prediction made the main method used to generate an analogy was that transformation. This outcome is in agreement with that of Clement's (1988) despite the fact his study sample was fundamentally different from that of the present study.

Responses from S13.13 and S15.14 illustrate the type of the nine remaining explanations given for the justification of option A. These students made the correct prediction simply by reasoning on the basis of their scientific knowledge.

> *Both of the bulbs will light up at the same time because both will fall at the same moment regardless of the weight in them.*

(S13.13)

> *What led me to this choice is that there is not any difference between the two boxes regardless of what is included in them.*

(S15.14)

The other seven students who chose option A without involving analogies in their responses provided explanations of similar type with those of S13.3 and S15.14.

Students did not base their explanations upon analogies in the case of option C. One of these two students was in Year 4 (10 years old) and the other one in Year 6 (aged 12 years). Although they did not generate an analogy, their explanations were examined in terms of the idea they used in their predictions.

> *Because the ant is much smaller than the elephant and thus falls with greater speed to the ground.*

(S10.15)

Bulb B will be first because the content of this box is much lighter and thus it will fall faster.

(S12.16)

These two responses differ from all of the other in terms of the idea being involved. These predictions could be explained on the basis of a p-prim activation; the spontaneous resistance p-prim identified by diSessa (1993). As diSessa commented, this p-prim can be activated in many situations and could also form the basis to understand numerous phenomena, for example “why a string gets taut when used to pull an object: The object resists motion.” (p.128). It seems that student S.10.15 and S12.16 had the thought that objects that weight less, compared with heavy ones, exert less resistance. This is exactly what resistance p-prim is all about. Perceiving mass as a kind of resistance, the lighter object resists less and less resistance in this case implies faster motion. The table below offers a summary of the findings derived from the analysis of the data collected from the questionnaire.

			student DID self-generate an analogy	student DID NOT self-generate an analogy	Total
A) Bulbs will light up at the same time (the correct, scientific one)	Involvement of the idea that heavy objects fall faster	Student DID Express the idea that heavy objects fall faster	***0***	***0***	0
		Student DID NOT Express the idea that heavy objects fall faster	***11***[b]	***9***	20
	Total		***11***	***9***	20
B) Bulb A will be first	Involvement of the idea that heavy objects fall faster	Student DID Express the idea that heavy objects fall faster	***73***	***43***	116
		Student DID NOT Express the idea that heavy objects fall faster	***3***	***25***	28
	Total		***76***[a]	***68***	144
C) Bulb B will be first	Involvement of the idea that heavy objects fall faster	Student DID NOT Express the idea that heavy objects fall faster	***0***	***2***	2
	Total		***0***	***2***	2
Total	Involvement of the idea that heavy objects fall faster	Student DID Express the idea that heavy objects fall faster	***73***	***43***	116
		Student DID NOT Express the idea that heavy objects fall faster	***14***	***36***	50
	Total		***87***	***79***	***166***

[a] 72 of these analogies generated via transformation, 3 via association and 1 from a formal principle
[b] 10 of these analogies generated via transformation and 1 via an equation (formal principle)

Table 4.2.3 Summary of the questionnaire analysis

The explanations examined above were classified as Direct Spontaneous explanations (DSE) because the analogies students used were generated without any provocation. In other words there was not any kind of lead from the part of the researcher to the student so as for the latter to provide an analogy as part of the explanation of option A, B and C. More analogies were used in explanations of different type (other than DSE) during the group discussions carried out after the administration of the questionnaire. The analysis of the interview transcripts is presented in the following paragraphs.

4.2.2 Analysis of group discussions.

As it has already been discussed, after completing the questionnaires students were interviewed about their responses to each novel situation in the test. As it was the case for every novel situation, interviews for the weight and gravity situation lasted of about five-six minutes for every discussion group, and followed up, to clarify and extend each student's responses to the open-ended question.

Except from using interview data for triangulation purposes, interview transcripts were read thoroughly and were examined for evidence of analogy generation in students' responses about what led them to make a particular prediction. With the responses to the multiple choice questions being written in the questionnaire scripts, it was not expected to found any differences in students' predictions and thus, the transcripts were analysed focusing on the explanations of the predictions with even more attention being paid to whether an analogy was being used or not.

Furthermore, since a variety of DSE (Direct Spontaneous Explanations) were observed in students' written responses of weight and gravity situation with more than half of the study sample spontaneously generating an analogy, even before starting the analysis of the transcripts it was not expected to find explanations of this particular type. To a certain extent, it was expected to identify explanations in which analogies were generated in another way, like ISE (Indirect Spontaneous Explanations) and PIE (Prompted Indirect Explanations) extensively discussed in the methodology chapter.

Nevertheless, this is not to say that it was highly unexpected to observe direct spontaneous analogies in students' transcripts, the assumption being made here is mainly that if students were to spontaneously generate an analogy they would do so when they were completing the weight and gravity open-ended question. There was still the chance that during group discussion the self-generation of analogies by several students might trigger their group peers to generate their own analogies, even if the latter did not theretofore involve an analogy in their written response. However, this could be better perceived as an indirect spontaneous explanation rather than a direct spontaneous one. This is because, in this case students would be clearly motivated by their classmates to generate an analogy in contrast to spontaneously generating an analogy and use it in their explanations.

From the analysis of the group discussions carried out for novel situation 1 (elephant and ant), there were ten more analogies identified in students' explanations of the option chosen. From these ten analogies, nine were coded as being generated via transformation and one via an association. Five of the explanations in which an analogy was involved were coded as ISE, four as PIE and one was identified as being a DSE. Following are some excerpts of the transcribed discussions showing the identification of students' analogies in terms of the generation method and the way of generating them (directly, indirectly or being prompted by the researcher).

Considering the following example from a student in school grade 4 who did use an analogy to explain the prediction during the conduction of group discussions:

> Interviewer**:** *In the one little box we have an elephant and in the other little box we have an ant. Ok?*
> *Students: Yes.*
> *Interviewer: The boxes are the same, their weight is the same and their dimensions are the same as well. Also we should not think that there is any wind blowing. Ok?*
> *Students: Yes.*
> *Interviewer: So, anyone who has answered that the bulb under the ant will light up first or that both bulbs light up at the same time? Has anyone given these answers?*
> Students*: No.*
> S10.17: *I did, bulb B will light up first because the content of the box is lighter.*
> Interviewer*: That is a great idea! All right! Do you want to tell us why?*
> S10.17*: Bulb B will light up first because the content of the box is lighter.*
> Interviewer*: Does this makes you think that it will it move faster??*
> S10.17*: Yes*
> Interviewer*: Could you please tell us what makes you think that?*
> S10.17*: Hm...I do not know.*
> Interviewer*: OK. Is there something similar that you have observed in your everyday life???*
> S10.17: *No.*

> Interviewer*: You have never seen a lighter object falling faster in relation to a heavier??*
>
> S10.17: *I do not remember.*
>
> Interviewer*: Ok. So for option B that states that the bulb located under the elephant will light up faster. As you have already mentioned the way of understanding it is that it* [the box] *is heavier and will fall faster, I want you to tell me what makes you think that heavy objects fall faster. What would you say to your classmate that argues that C is the right answer?*

In the above exchange S10.17 focused on the difference of mass, as the majority of students did, but the prediction made was the converse one according to which lighter means faster. This conception could be better understood from a p-prim perspective as it is discussed in the last part of the previous subsection (activation of spontaneous resistance p-prim). In this group discussion students explained once again that heavy objects fall faster giving some explanations with analogies that they wrote in the questionnaire. Then the interviewer questioned them further:

> Interviewer: *Except from the examples that your classmate gave us, I want you all to think and tell me things that you have observed and lead you in the conclusion that heavy objects fall faster.*

After a few, repeated examples (these were actually written in students' questionnaire scripts) and even before moving to the next question, 10-year-old students of this group were asked by the interviewer:

> Interviewer: *Does anyone have anything to add? Let's hear another example. Yes...*
>
> S10.18: *Me and my brother who is five and a half years old, we had jumped from a wall which was two meters high. We jumped simultaneously and I reached* [the ground] *faster, because I am heavier.*

In the latter case students were asked straightforward by the interviewer to provide an analogous case of the weight and gravity situation. This way, S10.18 generated an analogy for their explanation which was coded as PIE. As it can be seen from this response, the student focused on the element of difference of mass between the elephant and the ant and they generated an analogy by simply changing the two animals just like other students did during the discussion and as it was found in the written responses. However, instead of dropping two differently weighted objects they thought of a situation in which two persons jump. In this sense, the analogy is different from the situation and the analogy was coded as being generated via an association.

Also, it should be added here that the previous explanation of option C that student provided was already presented in the tables of the previous sub-section. The purpose of providing the full excerpt here is to serve as an exemplar of how PIE explanations were identified in the group discussions/interviews transcripts. Student S10.18, one student in Year 7 (13 years old) and two students in Year 9 (aged 15 years) generated an analogy when they were asked to provide an example of heavy objects falling faster. Except from S10.18's analogy, the analogies other students self-generated were formed via transformation.

The response by S12.19 typifies the ISE explanations offered by students aged 12 and 10 years. In the same transcript excerpt, S12.20's statement shows another example of an analogy being indirectly spontaneously generated (ISE type of explanation).

> Interviewer: *Has any kid answered that the bulb under the ant will light up first?*
> Students: *No.*
> Interviewer: *That the bulbs will light up together?*
> S12.19: *I did.*
> Interviewer: *This is another good idea! Could you please tell us why?*
> *S12.19: I have answered A, because I think that they will light up at the same moment.*
> Interviewer: *Ok... Could you please explain us what makes you think that both will light up simultaneously?*
> S12.19: *I have answered that they will light up at the same moment because I think of it as two pieces of concrete bricks, concealing the ant and the elephant in them, and I have written that it does not matter what amount of weight they contain inside them* [the concrete bricks]*, since they are made of cement they will fall together.*
> Interviewer: *What if they were not made of cement? Does it make any difference?*
> S12.19: *I do not know! I just think of them as being made from cement!*
> *Interviewer: All right, anyone who does not agree with this statement? What would you tell to your classmate? Everyone will speak! Let us start with your classmate next to you. What do you think?*

S12.20: *I answered that bulb A will light up first, because when there is an elephant-he is heavier than the ant- it is reasonable* [meaning for the box] *to fall faster.*

Interviewer: *I see! That is a great idea too! What makes you think that the elephant falls faster?*

S12.20: *Likewise when you have an apple and it is whole it will fall fast. If you only have the kernel it will fall very slow.*

Interviewer: *Thank you! Anyone else?*

S12.20: *I too answered the first bulb* [will light up faster] *because I performed a somehow alike experiment. I took a pack of flour in my one hand ,because I had seen once that it is heavy, and a pack of paper tissues and I let them fall together and the heavier was the flour, therefore it fell first.*

In the above exchange S12.19 has made the correct prediction. However, without any doubt S12.19 followed a faulty reasoning. This student thought of the two boxes as being made of cement and of their weight as being already great irrespectively to what they contain. This way, the student thought that the mass difference is not that great and made the prediction that the bulbs light up at the same time. The other two students, in an attempt to comment on their classmate prediction and explanation, they generated an analogy by focusing in the difference of mass between the elephant and the ant. This way, they generated an analogy by making a reference to other objects that they do differ in terms of mass and are left to fall from the same height (analogy generation via transformation).

In the following transcript excerpt, S12.21 student's statement shows how an analogy was spontaneously generated and involved in the explanation of A prediction option as being the correct one, which is actually the scientific acceptable one. Contrariwise with the reasoning of S12.19, this student followed a reasoning process which is compatible with the scientific view.

Interviewer*: Has any kid answered that the bulb under the ant will light up first?*

Students*: No.*

Interviewer*: That the bulbs will light up together?*

S12.21*: I did.*

Interviewer*: Good idea! Could you please tell us why?*

S12.21*: I have answered A, because I think that they will light up at the same moment.*

> Interviewer*: Ok! Could you please explain us what makes you think that both will light up simultaneously?*
>
> S12.21*: I cannot explain my answer, but it is like dropping from the same height a pen and a rubber. I did try that while I was doing the questionnaire I did the same thing with my pen and my rubber and the result was the one I have answered.*

As it is the case for the other type of explanations that students provided during group discussions, student S12.21 did pay attention in the difference of mass between the elephant and the ant but in this case the analogy generated was helpful in leading them to the correct prediction. Moreover, as they stated, the conduction of a kind of experiment did help them to confirm their thinking and choose the right prediction option. This response clearly reveals that reasoning on the basis of analogies not only leads to an incorrect prediction but there could be some cases in which it results in making correct predictions. A similar reasoning process was followed by a student who was 17 years old and spontaneously generated an analogy during the group discussion in order to explain option A.

Adding the analogies generated during the group discussion to those identified in the written responses increase the total number of analogies generated to 96 out of the 166 (approximately 58% of the total study sample).

With 58% of students involving analogies in their explanations it is reasonable to suggest that the generation and the use of analogies played a significant role in the process of making a prediction about this particular situation (novel situation 1). Moreover, the data showed that the most common way for generating an analogy was that of making a transformation to the original situation by changing only one element (the animals in which the difference of mass was identified).

Finally, it was found that most of the students that did involve an analogy in their explanations spontaneously generated it claiming that this analogy was part of their thought which led them to make a particular prediction. Interestingly, the analogies spontaneously generated led students to choose option B according to which heavy objects fall faster; an idea that is well identified in the literature about students misconceptions (Driver et al., 1985). Nevertheless, rather than interpreting students' ideas using a misconceptions perspective, it seems to be more appropriate to understand them from a p-prim one. This is because according to the findings of this situation, students' ideas seem to be encoded at a more abstract level in relation to phenomena they observe in their daily life rather than a knowledge structure which attributes faster motion to objects with greater mass.

Table 4.2.4 presents a summary of the results found through the data analysis of the questionnaire and the transcribed interviews about weight and gravity situation. For the construction of this table, the same approach with the previous table presented in the present section was used. SPSS was used to construct the table through cross tabulation test.

Although from the latter analysis of the group interviews there were more analogies identified in students' responses, there was not an association found between students' age and the use of analogies in the explanations (chi-square with one degree of freedom=4.132, p=0.388). This reinforces the previously made claim according to which, irrespective of the age of students, a common reasoning process for making a prediction for this situation was on the basis of analogies. However, there was a statistically significant difference found between students' age and the use of analogies which led to a correct prediction (chi-square test with one degree of freedom=4.500, p=0.034). Most of the students who reasoned on the basis of an analogy and made the correct prediction were in secondary education (only one was in primary, aged 12 years). It should be noted here that Fisher's exact test was not calculated for the predictions made as the frequency of the options chosen remained unchanged after the analysis of the group discussions.

Students' age			predictions in novel situation 1 (weight and gravity)			Total
			A) Bulbs will light up at the same time (the correct, scientific one)	B) Bulb A will be first	C) Bulb B will be first	
10	involvement of analogy in the written explanation of predictions	student **DID** self-generate an analogy	***0***	***20***	***0***	***20***
		student **DID NOT** self-generate an analogy	***0***	***16***	***1***	***17***
	Total			***36***	***1***	***37***
12	involvement of analogy in the written explanation of predictions	student **DID** self-generate an analogy	***1***	***21***	***0***	***22***
		student **DID NOT** self-generate an analogy	***1***	***7***	***1***	***9***
	Total		***2***	***28***	***1***	***31***
13	involvement of analogy in the written explanation of predictions	student **DID** self-generate an analogy	***3***	***13***	***0***	***16***
		student **DID NOT** self-generate an analogy	***0***	***13***	***0***	***13***
	Total		***3***	***26***	***0***	***29***
15	involvement of analogy in the written explanation of predictions	student **DID** self-generate an analogy	***4***	***18***	***0***	***22***
		student **DID NOT** self-generate an analogy	***4***	***9***	***0***	***13***
	Total		***8***	***27***	***0***	***35***
17	involvement of analogy in the written explanation of predictions	student **DID** self-generate an analogy	***5***	***12***	***0***	***17***
		student **DID NOT** self-generate an analogy	***2***	***15***	***0***	***17***
	Total		***7***	***27***	***0***	***34***
Total	involvement of analogy in the written explanation of predictions	student **DID** self-generate an analogy	***12***	***84***	***0***	***96***
		student **DID NOT** self-generate an analogy	***8***	***60***	***2***	***70***
	Total		***20***	***144***	***2***	***166***

Table 4.2.4 Summary of the novel situation 1 findings

4.3 Analysis of novel situation 2 and 3: burning a candle, burning iron wool

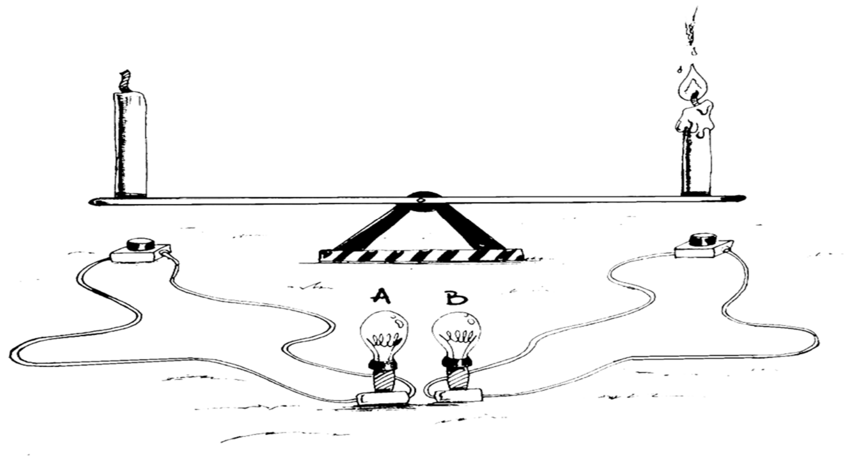
This subsection presents the analysis of two novel situations, the burning a candle and burning iron wool. It is divided in two parts. Novel situation 2 and novel situation 3 are analysed separately in the first and second part respectively whereas within this second part a synthesis of the findings from the two questions is offered.

It was decided to present the analysis of these two situations in the same section due to the similarities that they share. As it was discussed elsewhere (subsection 3.5.3), these two situations seem to be quite similar, and yet different to some extent. The difference is related to the assumption made that students could respond to these two different questions by being based upon the same idea. The application of the same idea in these two different situations could lead students to the correct and scientific prediction in one case and to an incorrect one in the other.

The reason for the choice adopted is that a presentation of these two situations analysis within the same section better reflects the similarities and differences in the prediction that students made as well as the explanations provided as justifications for the former.

Adopting the same approach, the presentation of the data analysis is in the same format with the previous situation. For each of the two situations examined here, the analysis of students' predictions is firstly presented followed by a discussion for the responses given in the open ended question in which students were asked to explain what led them to the prediction they made.

4.3.1 Analysis of novel situation 2: Burning a candle



Two identical candles are balanced on a beam. After, we light one of the candles as shown in the figure. Will one of the bulbs be switched on? If yes, which one of the two?

A) Bulb A *B) Bulb B* *C) None of them*

After the administration of the questionnaire to the students, the guidance given for this situation was that the two candles were identical when they were placed on the beam. After being placed on the beam, one of them was being lit. Also, older students of secondary education were told that the beam was of that high sensitivity that could respond in any mass differences.

As it is the case for every situation, the analysis of the present one was carried out in terms of the options chosen in the multiple choice question and the justifications provided for them. Moreover, the responses in the open ended question were used so as to corroborate the option being chosen in the first question (the multiple choice one). In the same vein the explanations that students provided as well as the generation of analogies were informed by triangulating on the basis of the written responses provided in the open-ended question and the transcriptions of the group interviews.

The results from the multiple choice question about the options that students chose for the burning a candle situation and the generation of analogies across the five age groups are presented in the following table (Table 4.3.1).

student's age			*prediction about the novel situation 2 (burning a candle)*			Total
			C) None of the two bulbs	*A) Bulb A (the correct, scientific one)*	*B) Bulb B*	
10	involvement of analogy in the written explanation of predictions	student **DID** self-generate an analogy	***0***	***13***	***4***	***17***
		student **DID NOT** self-generate an analogy	***0***	***18***	***2***	***20***
	Total		***0***	***31***	***6***	***37***
12	involvement of analogy in the written explanation of predictions	student **DID** self-generate an analogy	***1***	***16***	***0***	***17***
		student **DID NOT** self-generate an analogy	***1***	***13***	***0***	***14***
	Total		***2***	***29***	***0***	***31***
13	involvement of analogy in the written explanation of predictions	student **DID** self-generate an analogy	***0***	***14***	***1***	***15***
		student **DID NOT** self-generate an analogy	***0***	***13***	***1***	***14***
	Total		***0***	***27***	***2***	***29***
15	involvement of analogy in the written explanation of predictions	student **DID** self-generate an analogy	***2***	***10***	***1***	***13***
		student **DID NOT** self-generate an analogy	***2***	***17***	***3***	***22***
	Total		***4***	***27***	***4***	***35***
17	involvement of analogy in the written explanation of predictions	student **DID** self-generate an analogy	***0***	***15***	***0***	***15***
		student **DID NOT** self-generate an analogy	***4***	***13***	***2***	***19***
	Total		***4***	***28***	***2***	***34***
Total	involvement of analogy in the written explanation of predictions	student **DID** self-generate an analogy	***3***	***68***	***6***	***77***
		student **DID NOT** self-generate an analogy	***7***	***74***	***8***	***89***
	Total		***10***	***142***	***14***	***166***

Table 4.3.1 Students' predictions and self-generation of analogies in novel situation1 (burning a candle).

The table above shows how many students from each age group chose each of the three options and how many students used an analogy in their explanations concerning what led them to that choice.

The cross tabulation statistical method was used in this situation and expected values were calculated. These values were in accordance with the actual values suggesting that students' choices were at almost exactly the same level as they would be expected to be if there was no correlation between age and option chosen. However, these values are not presented here because they could not be used for further statistical analysis to show if this agreement was statistically significant or not (many of the actual values in Table 4.3.1 were less than one and more than 20% of the expected values calculated were less than five). Instead, Fisher's exact test was used which confirmed that there was no correlation between the option students chose and their age (Fisher's exact test=13.877, $p=0.074$).

It can be seen that option A (the bulb A will be switched on) was chosen the most frequently. There were only few, slight, differences in terms of the percentage of students aged 10, 12, 13, 15 and 17 years that chose option A. Overall, 142 out of the 166 students chose option A (this represents 86% of the study sample).

Despite the fact that this prediction was the scientifically correct one, an appropriate and scientific explanation for having made this prediction was very uncommon. As discussed previously (Chapter 3; subsection 3.5.2), in the open ended question, students ought to involve the role of oxygen and the particulate model of matter in order to provide a scientific explanation. Only two 17 year-old students provided such an explanation. The following is the response of one of these two students, showing what was considered as being a scientific explanation:

> *I have answered that bulb A will be switched on. When the candle burns there is carbon dioxide being given off if we have a complete combustion and some carbon monoxide in case of the combustion being incomplete. Therefore the mass of the candle decreases after burning.*
>
> (S17.1)

This low percentage of students' achievement to choose the scientific prediction and explain that accordingly reflects similar findings from studies carried out by several researchers in this area of students' understanding of burning a candle process (e.g., Meheut et al., 1985; BouJaoude, 1991). Only three out of the 166 students explained their predictions in terms of the oxygen reacting with the carbon particles in the candle. The latter supports Kind's (2004) conclusion that students confront difficulties in recognising the role of oxygen in the reaction.

The majority of students who chose option A as being the correct one involved in their explanations an idea that is compatible with the scientific perspective. The reaction of the oxygen with the material that the candle is being made of (mostly wax, paraffin) produces carbon oxides which evaporate and therefore, the mass of the candle decreases. The result of this burning process is the idea that the vast majority of students who chose option A expressed in the justification of their prediction. According to this idea, burning makes objects lose weight.

There were 103 out of the 142 cases in which students explained option B using the idea that there is a decrease in mass of objects being burnt. Although these 103 students correctly chose option A, the foundation to their prediction was flawed as the students simply believed that there is a mass decrease without acknowledging the role of oxygen or justifying their predictions using the particulate model of matter.

From these 142 students, 48 students chose option A and based their explanation only upon the aforementioned idea and some of them (including students in secondary education) insisted on that justification during the group interviews claiming that this is how things are, albeit they were asked to elaborate further on their ideas. They stated that there is no need to explain it further; objects lose their weight when they burn. The following two responses show how students explain their prediction by being based exclusively upon this idea:

> *I have chosen that bulb A will be switched on. Since the candle is burning, it is getting smaller and smaller. If we leave it for a long time and the burning process finishes, I mean when the flame burning the candle extinguishes, nothing will remain and the other bulb will be switched and this is due to the weight shifting towards the other side of the beam.*
>
> (S13.2)

> *I answered Bulb A will light up first. If the candle is burning for a long time it will melt and thus it will lose its weight and the beam will lean to the right, to this side that the candle is not lit.*
>
> (S15.3)

Although these two explanations are very similar, in the latter there is one more idea involved. S15.3 appears to understand the burning process of the candle as something being melted. This idea has also been identified in other studies. Studies have suggested that 25% of students aged from 11 to 14 years describe the burning process as simply something being melted (Meheut et al., 1985; BouJaoude, 1991). However, the percentage of younger students who gave such an explanation in the present study was significantly higher in comparison to the aforementioned studies (44% of students aged from 10-13 years described the process as something being melted).

As the focus of this study was not only the analysis of the responses in terms of the predictions made and the ideas used in the justification of the latter, the explanations were examined with regard to the use of analogies. A closer examination of the explanations in terms of self-generated analogies could reveal where this idea of burning objects losing their weight stems from.

The results from the open ended question and the transcription of the interviews concerning how many students used an analogy in their explanation about what led them to choose option A are presented below (Table 4.3.1). With option A being the one most frequently chosen across all ages, the majority of the analogies was generated by students in their attempt to explain why A is the correct option. Approximately one out of two students who chose A used an analogy in their explanations. Almost equal percentages of students aged 10, 12, 13 and 17 years explained option A by self-generating an analogy whereas slightly different was the case for the 15 year-old students of the present study. The actual percentages are 42%, 55% 50%, 37% and 54% of students in Years 4, 6, 7, 9 and 11 respectively. Nevertheless, these slight differences were not statistically significant (Fisher's exact test=2.514, p=0.654).

The majority of these analogies were generated spontaneously as they were identified in students' responses written on the space the questionnaire included to provide an explanation to the open ended question. Therefore, 64 out of the 68 explanations in which an analogy was identified were coded as DSE. The remaining four cases were identified in the group interview transcripts. Of these, two were explanations in which 10-year-old students used an analogy in their explanations attempting to elaborate more on their response (coded as ISE), whereas the other two were analogies that were generated when one 13 year-old and one 17 year-old were asked to provide an analogous case that could or did help them to make their predictions (these being coded as PIE). Irrespective of how the analogies were generated, in 55 of these 68 cases students used the analogy in their explanations in combination with the ideas of a decrease in mass of burning objects.

Of these 68 explanations, in which an analogy was identified, 62 were coded as being generated via a transformation. In these explanations students appeared to generate the analogy by simply focusing on one element of this situation. They focus their attention on the process of the candle being burnt. By changing the element of the object being burnt (the candle), they self-generated an analogous case and they applied the findings/conclusions of the latter to the novel situation in which they were asked to make a prediction. The following three responses in the questionnaire script attest to this generation method:

> *I think that this is like a piece of wood being burned into the fireplace. I remember that I had once taken a piece of wood and I had placed on it two pieces of paper and I had lit the one and the other was heavier so it fell down. Thus, B is the correct answer, the one I chose.*
>
> (S12.4)

> *I chose A bulb to light up. It is like the case of a piece of paper. After being burnt will not have the same weight anymore, it becomes lighter. I think that the same happens with the candle, it loses its weight as it gets burnt.*
>
> (S15.5)

> *I chose that bulb A switches on, the one that is underneath the candle not being lit. I can't explain it further but I think that it is like smoking a cigarette. I mean this is what came to my mind. When we light up a cigarette it burns and it becomes smaller and smaller. After the* cigarette *has been smoked it does not weight as much as before.*
>
> (S17.6)

There is a degree of similarity between these three exemplars as well as to all the other explanations in which analogies were identified as being generated via transformation. Students focused on the element of an object being burnt in order to come to the conclusion that burning objects lose their weight or to justify what makes them believe that the latter is a correct idea. The only difference across the five age groups was the element of the object being burnt that students focused on to generate an analogous case. Some of them mentioned a decrease in mass of a book and a plastic egg box being burnt, whereas others provided the analogous case of an igniting match.

The remaining four out of the 68 analogies which were not generated via transformation were analogies used in students' explanations of option A which were formed via an association. In this case, these four students, one from Year 4, two from 6 and one from Year 7, aged 10, 12 and 13 years respectively, claimed that they were led to this option by being reminded of an analogous situation in memory that was different in many ways from the burning a candle situation. These students focused on the element of the liquid that flows while the candle is lit and they generated an analogous situation different from the situation they were presented with. Notwithstanding, this analogous case led students to make the same prediction (option A) as it is the case for students that used an analogy generated via transformation. An illustration of this generation method is shown below with reference to questionnaire script of a 12 year-old student:

> *I answered that bulb A will light up because when something is burning it becomes lighter. This is like the example in which we have two ice cubes and one of them melts there is water being flowed. If they are located on a beam, the one that will not melt will be heavier, and therefore the beam will lean under its weight.*
>
> (S12.6)

Similar to this response were the other three explanations in which the analogy was generated via association. Students used the same reasoning process and came to the same conclusion (burning objects lose weight, thus option A is the correct one) by using another material instead of an ice cube (e.g., an ice cream being melted, a wet sponge being squeezed and water being flowed).

The four explanations offered above suggest that students' idea of burning objects weighing less is based on everyday experiences. It is easier to understand this idea as deriving from experiential knowledge such as lighting a fire in a fireplace with the remaining ash being lighter than the wood burnt rather than a theoretically grounded conception. Furthermore, this idea is neither incorrect when it is applied to the experiences it is based on, nor in this burning a candle situation.

This way, 142 students chose the right and scientific option but only two gave a scientifically accurate explanation. Moreover, 103 of them expressed the idea that burning objects lose mass whereas 68 of them explicitly explained either in their written responses or during the group discussions/interviews what led them to choose option B and what made them think that when an object burns, there is a decrease in its mass. Students who chose option A, but did not use an analogy in their explanation, or justified it in terms of the idea mentioned above, used a sequence of events, explaining what happens rather than why this happens. These responses resembled descriptions rather than explanations and therefore were not coded.

Although the vast majority of analogies were identified in students' explanations of option A, there were written responses in which an analogy was used for the other options of this situation as well. Students who chose option B or C made their choice on the basis of analogies (Table 4.3.1). There were one student aged 15 years and two aged 12 years who used an analogy in order to explain what led them to choose option C whereas four students aged 10 years and two students aged 13 and 15 years respectively who used an analogy for option B.

All of these analogies were identified in the written explanations of students' responses and therefore they were coded as DSE. Moreover, the generation method of the analogies in explanations provided for option A was that of being based on a transformation. On the other hand, generation via association was the generation method of the analogies used to explain option C. Consider the following two examples from the scripts of two students:

> *I think that the candle that is on side B switches on because when the candle burns heat melts it and as a result it loses parts of its weight due to the wax drops that flow. But, this candle wax drops to the bottom of the candle, on the beam and somehow the candle regains its initial weight. That is very similar with an ice cream left out for a long time. There is cream being flowed and thus the ice cream loses its mass. But again, if we put the ice cream back into the fridge it gains its shape and mass.*
>
> (S13.7)

In this case, the student S13.7 was led to choose option B by being reminded of an analogous situation in memory that was different in many ways from the original situation. In agreement with the claim made by the student S12.6, the focus here was on the element of candle wax being flowed as the candle burns. As it is mentioned above this analogous case was expressed by other students that were led to choose option A and claimed that the mass of the ice cream decreases. Student S13.7 came to a different conclusion, albeit they used the idea of a burning object losing its weight. This difference reveals that the application of the same idea results in making correct predictions in the first case and wrong in the latter. The following response shows how the generation of the same (or similar) analogy has the potential to lead to different predictions.

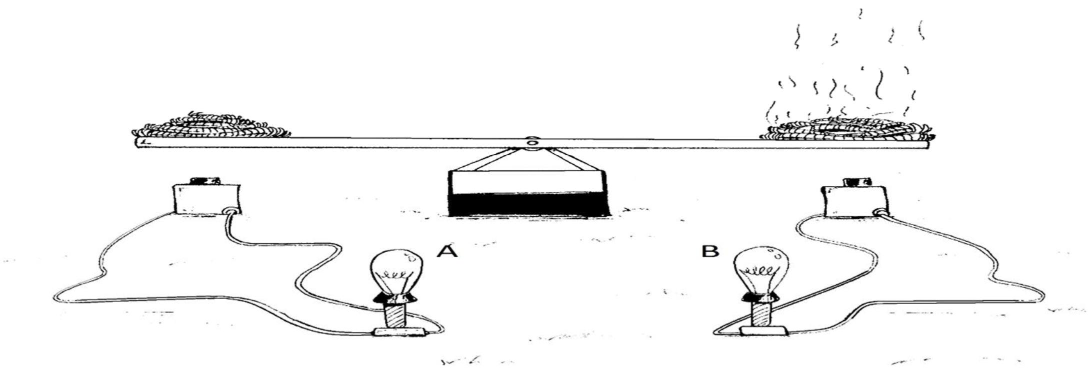
> *I chose that none of the bulbs switch on. I have observed a similar situation with that at the church, on Holy Saturday night. I usually hold a candle that burns, but I do not see, I do not feel any difference regarding its weight, I mean the mass of the candle.*
>
> (S10.8)

In the above explanation, the student appeared to generate an analogous case almost identical with the burning a candle situation. Student S10.8 focused on the process of the candle being burnt and simply generated another example of that situation. Other students across the five age groups who generated similar analogous cases referring to candles being burnt came to a different conclusion and chose option C.

The above two responses reinforce the suggestion that the explanations offered and the ideas involved do not seem to be theoretically grounded. Rather, any conceptions involved in the justifications of students' predictions as well as the justifications themselves could be better perceived as being related to students' everyday experiences.

The following analysis of the burning steel wool situation shows whether there are any differences in the predictions made about these two quite similar situations. More importantly, it reveals if students used a similar way of approaching the situation with the one presented above in order to make their prediction about the burning iron wool situation.

4.3.2 Analysis of novel situation 3: Burning steel wool



Two wire sponges which have the same weight are balanced on a beam. After, we light up one of them. Will one of the bulbs be switched on? If yes, which one of the two?

A) Bulb A *B) Bulb B* *C) None of them*

The instructions given after the administration of the questionnaire were the same with those provided for the burning candle situation. It was stressed that the beam is of high sensitivity and can respond to any mass differences and that the steel wools were identical before one of them being lit. Moreover, students were told that steel wools burn. In order to convince them and make clearer to them what it is meant by saying that one of them is lit up, an image was shown. This image is presented below (Image 4.3.2).

Image 4.3.2 [Untitled photograph of steel wool being burnt] (n.d.) Retrieved April 21, 2012, from http://mylespower.co.uk/2013/06/27/remake-of-alexs-burning-iron-video/img_1992/

Similarly to the previous case, the analysis of this situation was carried out in terms of the predictions made and the explanations responses that students provided concerning what led them to choose an option and by triangulating between the two sources of data (the questionnaire and the group interviews). Table 4.3.3 below shows what options students chose for the burning steel wool situation as well as the frequency of analogy generation in students' explanations across the five age groups. SPSS software was used for this table and cross tabulation tests were used to analyse the data. Expected values are not presented in this case as well and any statistical tests were carried out using Fisher's exact test.

student's age			prediction about the novel situation 3 (burning iron wool): C) None of the two bulbs	A) Bulb A	B) Bulb B (the correct, scientific one)	Total
10	involvement of analogy in the written explanation of predictions	student **DID** self-generate an analogy	*0*	*17*	*0*	*17*
		student **DID NOT** self-generate an analogy	*0*	*17*	*3*	*20*
	Total		*0*	*34*	*3*	*37*
12	involvement of analogy in the written explanation of predictions	student **DID** self-generate an analogy	*1*	*12*	*0*	*13*
		student **DID NOT** self-generate an analogy	*1*	*17*	*0*	*18*
	Total		*2*	*29*	*0*	*31*
13	involvement of analogy in the written explanation of predictions	student **DID** self-generate an analogy	*0*	*8*	*1*	*9*
		student **DID NOT** self-generate an analogy	*0*	*20*	*0*	*20*
	Total		*0*	*28*	*1*	*29*
15	involvement of analogy in the written explanation of predictions	student **DID** self-generate an analogy	*1*	*11*	*1*	*13*
		student **DID NOT** self-generate an analogy	*2*	*16*	*4*	*22*
	Total		*3*	*27*	*5*	*35*
17	involvement of analogy in the written explanation of predictions	student **DID** self-generate an analogy	*1*	*10*	*1*	*12*
		student **DID NOT** self-generate an analogy	*6*	*16*	*0*	*22*
	Total		*7*	*26*	*1*	*34*
Total	involvement of analogy in the written explanation of predictions	student **DID** self-generate an analogy	*3*	*58*	*3*	*64*
		student **DID NOT** self-generate an analogy	*9*	*86*	*7*	*102*
	Total		*12*	*144*	*10*	*166*

Table 4.3.3 Students' predictions and self-generation of analogies in novel situation 3 (burning steel wool)

From the 166 scripts and the group interview/discussion settings, it was found that only 12 students chose option C as being the correct one. This represents 7% of all responses. Although one out of four 12-year-old students that participated in Driver et al.'s (1985) study made the same prediction of steel wool remaining unchanged after burning, the percentages here are significantly different. Only two out of the 31 students at this age made such a prediction whereas, this prediction was more frequently made by 17-year-old students (seven out of 34). Moreover, other studies (e.g., Driver et al., 1985; Barker, 1990) in which students made this prediction claimed that the remaining ash is still the same iron wool and therefore they could not see any reasons causing a mass change. In the present study, the majority of the students that chose option C students did not provide any explanations about option C. Most of these students did not believe that steel wool can be burnt and thus they explained their prediction by simple stating that there is not any mass change.

In sharp contrast with the results of the previous novel situation (burning a candle), in this situation only ten out of the 166 students chose the correct option. Nevertheless, in both situations students did not provide a scientific explanation for the correct option. In terms of the prediction made, significantly lower is the number of students who made the scientifically accepted one in comparison to other studies which investigated students' ideas of the same phenomenon (Driver et al., 1985; Andersson, 1986; Barker, 1990). Moreover, in Driver et al.'s study, there were few students who provided the scientifically correct reason for their prediction. Contrariwise, in the present burning steel wool situation, none of the students provided an accurate and scientific justification of the correct prediction (option B).

As it was discussed in the methodology chapter, in responding to this question in a scientific way, students ought to have an understanding of one substance changing into another that weighs more. More importantly, as Kind (2004) argued, the role of oxygen is the key concept in order to approach the burning steel wool phenomenon in a scientific way. In sharp contrast to other studies (Driver et al., 1985; Andersson, 1986; Barker, 1990) in which students of the same age acknowledged the role of oxygen in the burning process, irrespectively of the prediction made, all of the students in this study did not reference the role of oxygen, nor did they mention that one substance can change into another as the formers did, in order to explain options A, B and C.

In contrast to the burning a candle situation, in the steel wool situation the iron wool has chemically combined with oxygen during the burning process and thus, having oxidized to form an 'ash' of iron oxide, its weight would increase (for more details see chapter3; subsection 3.5.3 as well as the appendix). None of the three, one, five and one students aged 10, 13, 15 and 17 years respectively gave such a justification for their choice of option B.

None of the students made any references to the chemical combination involved in the burning process and this could explain students' failure in making the correct prediction in combination with providing a scientifically correct justification. The majority of these students focused on describing what happens instead of why the phenomenon happens. However, there were three cases in which students explained their correct prediction (option B) by using an analogy and their explanations revealed their reasoning process. The analogy these three students used was identical with the one that the same students self-generated in the burning a candle situation. The following response, illustrates this type of analogy:

> *I chose option B because I think that as we light the steel wool there is a boost from the fire acting upon it. This boost makes it move downwards. I can't explain why that happens but this reminds me of how rockets are pushed forward simply by throwing backwards something like a fire.*
>
> (S13. 9)

In the above example the student appears to be reminded of an analogous situation in memory, that of rockets, which differs in many aspects from the steel wool situation but for the student still has important similar features. This generation method was identified as being that of association. The other two explanations in which students used an analogy were almost similar (one of them instead of rockets referred to fireworks in order to justify the boost that makes the burning steel wool move downwards) and they were coded as being generated via association. Moreover, these analogies were identified in students' questionnaire scripts and thus, the explanations were coded as DSE.

It is evident that students constructed their explanations by using analogies deriving from situations of their daily experiences. Without any doubt this reasoning is incorrect in the case of the burning iron wool situation whereas it is correct and can lead to a scientific prediction in the burning a candle one. Students who chose the correct and scientific option in the burning a candle situation, were led to an incorrect prediction in the burning wire wool situation by applying the same idea of a decrease in mass of burning objects. According to the results, 88 of the 144 students that chose bulb A switching on, involved this idea in this explanation. This represents 61% of all option A explanations.

Although, this percentage is lower in comparison to students' use of this idea that burning objects lose weight in the justification of option A in situation 2, it is plausible to assume that more than 88 students used this idea in order to make their predictions in the burning steel wool situation. This is because students explained option A in the latter situation by simply claiming that it is similar with that in the first question and that the same reasons led them to make their prediction. Therefore it could be assumed that they used the idea of burning objects becoming lighter, albeit they did not explicitly mention it.

Similar is the case with the use of analogies in students' explanation responses of option A. Only 58 out of the 144 students (Table 4.3.3) used an analogy in order to explain what led them to make the prediction that bulb A switches on. Nevertheless, students, who generated an analogy in an attempt to justify their choice of option A in the burning a candle situation, made the same prediction in this situation and explained it by simply stating that the reasons are identical with those in the first situation. Some of them did not justify their prediction at all and they simply responded that they had already written what led them to this option in the first question. However, these responses were not coded as explanations in which an analogy was involved as students did not self-generate an analogy. It might be assumed that students used an analogous case in their explanations, that of the burning a candle situation but this would not be perceived as a self-generated analogy but rather as an analogy provided by the researcher.

As it has already been mentioned in the previous paragraph, the most popular option across the five age groups was that of option A (bulb A will be switched on). Although there was not an association found between students' age and the use of analogy in their explanations (chi-square with four degrees of freedom=1.877, p=0.758), there is a significant association between age and the option chosen (Fisher's exact test=18.159, p=0.006). The effect size in the latter case is small according to Cohen's (1988) guidance (Cramer's V=0.106). There were slight differences identified among the five age groups with the percentage of students that chose option A being 92%, 93%, 96%, 77% and 76% of students aged 10, 12, 13, 15 and 17 years respectively. As the data show this difference does not mean that older students made the correct prediction more frequently. More students in Years 7 and 9 chose option C in comparison to the younger students of the study sample. Whatever the case, these results are quite similar with the percentages of students who made the same prediction in the burning a candle situation.

In addition to the use of the same idea of objects losing their weight when they get burnt, it was found that 58 out of the 144 students that chose option A used the same or very similar analogies in their explanation with the one they involved in the burning a candle situation. In agreement with the way of generating analogies in the previously analysed situation, the vast majority of the analogies in this case were generated spontaneously as they were identified in students' questionnaire scripts. From the 58 explanations, 56 included a spontaneously generated analogy and thus these explanations were coded as DSE. The other two analogies were identified in the group interview transcripts. They were found in a 10-year-old student's response who was attempting to elaborate more on the explanation provided (coded as ISE) and the other one was provided by a 17 year-old student who was asked to give an example that could be helpful in making a prediction (coded as PIE).

All of these analogies were coded as being generated via a transformation. This is because students generated an analogy by simply focusing on the element of the steel wool being burnt. By changing the element of the object being burnt and by replacing it with another object, students self-generated an analogy and they applied the findings/conclusions to this situation. The following three responses show how students explain the choice they made (option A):

> *I chose that bulb A lights up. The steel wool that is getting burnt loses weight! I have observed that wood becomes lighter when it burns and I have seen that happening with the firewood my father places into the fireplace. So, the burning steel wool becomes lighter causing the other one to press the button and turn the bulb on.*
>
> (S12.10)

> *I chose A because when burning, the wire sponge loses its weight. This is very similar with the example in which we place a stack of papers on a beam, on both sides. If we set one side on fire, then the stack will get burnt losing thus its weight.*
>
> (S15.11)

> *I have replied that bulb A switches on. This is because when burning, there is a decrease in the mass of the wire sponge. It is like having two matches on a beam. If we set one of them on fire, it gets burnt losing its weight and thus making the beam lean to the other side.*
>
> (S17.12)

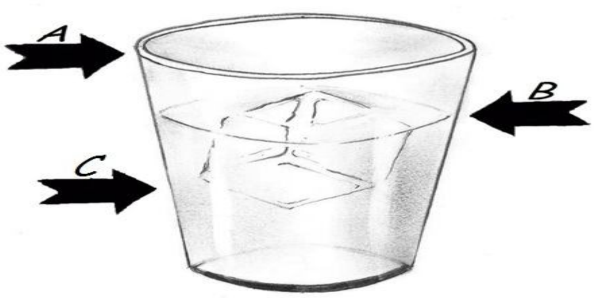
What can be seen from these excerpts is that they are in many ways similar with the majority of the explanations that students provide for the burning a candle situation. Not only the generation method was the same but also the analogies generated were very similar and in many cases identical in the two situations. Students in both cases have attempted to apply findings deriving from the analogous cases which were based on their everyday experiences to the novel situation they were presented with.

Although the reasoning was the same in both cases, the predictions made were different in terms of accuracy. In the first case, students were led to a scientific prediction whereas in the burning steel wool situation students chose a wrong option, albeit in both cases the reasoning was not the scientific one. In other words, students' ideas of objects being burnt are not only incorrect in relation to the experiences they are based upon but moreover they can lead to a correct prediction as it happened with the burning a candle situation.

From all the excerpts offered above, it is evident that students' conceptions of objects being burnt were not theoretically grounded but rather based on a collection of life experiences and explanations of the physical world in which they live. The most common underlying idea identified in students' responses is that there is a decrease in the mass of objects being burnt. When students talked about combustion they described that in terms of something disappearing. There is clear evidence in students' explanations that this idea is a reflection upon experiences like the firewood being burnt and the remaining ash, which is less bulky than the wood and the coal, being lighter (this analogy was the one mostly expressed in the present study).

In other words students have made their observations well and have come up with the logical conclusion that the remaining ash of an object being burnt is lighter than the original material. This is why their conclusions cannot be described simply as being incorrect and theory-like but rather, as being easier to be understood as fragmented knowledge. This is because, according to the findings of these two situations examined here, this idea seems to be related to students' experiential knowledge rather than being a stable knowledge structure concerning the process of burning and any mass changes.

4.4 Analysis of novel situation 4: Melting an ice cube in a glass of water.



When the ice-cube melts, which of the three arrows will point at about the same level as the water level in the glass?

A) Arrow A *B) Arrow B* *C) Arrow C*

This subsection presents the analysis of the fourth novel situation which examined what happens to the level of the water in a glass with an ice cube when the latter melts. By triangulating between the three sources of data, the responses were analysed in terms of the predictions made (the options students chose) and the explanations provided for them. Responses to the open ended question were used to corroborate the option chosen in the first question (multiple choice).

In this situation, the only guidance given to the students concerned instructions about the place of the arrows. What was made clear was that the question asked them to predict which one of the three arrows shown will point at about the same level of the water. They were told, however, that if they think that the level of the water gets above or below the place that arrow B points that they could use A or C arrows respectively.

The number of students that chose options A, B and C for this situation as well as the frequency of students involving an analogy in their explanations across the 5 age groups are shown in the table below (Table 4.4.1). As it can be seen, option A was the most frequently chosen one. There was a significant correlation between the prediction students made and their age (Fisher's exact test=16.375, p=0.042). The effect size is small to moderate according to Cohen's (1988) guidance (Cramer's V=0.220). In the lower ages there were smaller proportions making the correct prediction.

Students aged 10 and 12 years chose option A almost at the same level, whereas the frequency of students aged 13, 15 and 17 years in choosing option A was different. This discrepancy is likely to be the result of the greater achievement of secondary education students in making the correct prediction. From the 166 students who took part in this study, 127 chose option A (the prediction students were expected to choose as the analysis of this novel situation in the methodology chapter was supported). This represents 76% of the study sample.

student's age			prediction about the novel situation 4 (ice cube in a glass)			Total
			A) Arrow A	B) Arrow B (the correct, scientific one)	C) Arrow C	
10	involvement of analogy in the written explanation of predictions	student DID self-generate an analogy	***16***	***1***	***0***	***17***
		student DID NOT self-generate an analogy	***16***	***0***	***4***	***20***
	Total		***32***	***1***	***4***	***37***
12	involvement of analogy in the written explanation of predictions	student DID self-generate an analogy	***16***	***1***	***0***	***17***
		student DID NOT self-generate an analogy	***11***	***2***	***1***	***14***
	Total		***27***	***3***	***1***	***31***
13	involvement of analogy in the written explanation of predictions	student DID self-generate an analogy	***10***	***4***	***0***	***14***
		student DID NOT self-generate an analogy	***10***	***4***	***1***	***15***
	Total		***20***	***8***	***1***	***29***
15	involvement of analogy in the written explanation of predictions	student DID self-generate an analogy	***13***	***4***	***0***	***17***
		student DID NOT self-generate an analogy	***13***	***3***	***2***	***18***
	Total		***26***	***7***	***2***	***35***
17	involvement of analogy in the written explanation of predictions	student DID self-generate an analogy	***11***	***4***	***0***	***15***
		student DID NOT self-generate an analogy	***11***	***7***	***1***	***19***
	Total		***22***	***11***	***1***	***34***
Total	involvement of analogy in the written explanation of predictions	student DID self-generate an analogy	***66***	***14***	***0***	***80***
		student DID NOT self-generate an analogy	***61***	***16***	***9***	***86***
	Total		***127***	***30***	***9***	***166***

Table 4.4.1 Students’ predictions and self-generation of analogies in novel situation 4 (Melting an ice cube in a glass of water)

One of the reasons that led students to make an incorrect prediction was that they did not consider this situation in terms of floating. They explained this situation by simply stating that the ice cube just melts and changes into water. This is a common idea reported by Cosgrove and Osborne (1981) who examined students' views about ice cubes melting with the study sample (8-17 years olds' ide-as were investigated) being quite similar to that of the present study (see more details in chapter3; subsection 3.5.6). Many of the students who chose option A had this idea as a starting point in their explanations and combined it with the idea that when something melts there is a change in the vol-ume it occupies confusing the objects mass with the volume that mass occupies. This type of confu-sion between mass and volume has been reported in other studies as well (e.g., Driver et al., 1994).

From the 127 students who chose option A, 73 explained their choice by drawing on the idea that water would be added because the ice cube melted. Also, there were 20 (six, three, four and six and 1 students aged 10, 12, 13, 15 and 17 years respectively) whose explanations was merely based up-on this idea without using an analogy or making a reference to any other ideas. This type of explana-tion is illustrated in the following two responses:

> *I believe that since the ice cube is iced water when it will melt, the level of water in the glass will raise because it will add more mass in the existing amount of water that the glass contains. That is why I think that Arrow A will be point at the water level in the glass.*
>
> (S12.1)
>
> *I have chosen A. If you add an ice cube into a glass with water and leave it there for a long time, this ice mass will melt and increase the volume of water the glass. Therefore, A is the right answer.*
>
> (S15.2)

All the students who used this idea in their explanations appeared to have a very similar understand-ing of this situation. According to their justification, the ice cube melts and it becomes water. This amount of water should be seen to add to the volume of the existing water thereby raising the overall level of the water. Interestingly there was no evidence of students considering the removal of the volume occupied by the mass of the submerged ice cube. The latter did not help these students to make the correct prediction.

Also, 53 of the students that chose option A did not only use this idea but also used an analogy in their explanations, whereas there were 13 students that chose the same option and explained their prediction simply by using an analogy. A closer examination of these explanations could reveal what makes students understand this situation by thinking that water should be added just because the ice cube melted.

As the Table 4.4.1 shows, 80 students reasoned on the basis of analogies in order to make their predictions (48% of the study sample). There was not a significant difference between the age of the students and the use of an analogy in their explanation (chi-square with four degrees of freedom=0.851, p=0.931). The fact that approximately one out of two students used an analogy in their explanations would suggest that the analogy played a significant role in their reasoning and subsequently in the prediction made about this situation.

With option A being the most common prediction made across the five age groups, the majority of the analogies were generated by students who attempted to explain this particular prediction. More than half of the students (Table 4.4.1) who chose option A used an analogy in their explanations of their predictions. Almost equal percentages of students aged 10, 12, 13 and 17 years explained their choice by self-generating an analogy, whereas slightly different was the case for the 12 year-old students. Half of the students aged 10, 13, 15 and 17 years used an analogy in the explanation of option A, whereas the percentage for the 12-year-old students was higher (59%). At least one out of two students who chose A prediction option used an analogy in their explanations and this would suggest that the generation of analogy played a significant role in leading students to an incorrect prediction.

Of these 66 explanations of option A in which an analogy was used, 62 were coded as DSE as they were identified in students' questionnaire scripts. The remaining four analogies were identified in students' responses given during the group interview settings. One of these explanations was coded as PIE because it was generated by a 13 year-old student who was asked to provide an analogous case that could be helpful in making a prediction about this situation. The other three were analogies generated when one 10-year-old and two 12-year-old students were asked to elaborate more in what they wrote in the questionnaire and thus, these explanations were coded as ISE. The nature and the generation method of these analogies are examined in the following paragraphs.

The majority of these analogies were coded as being generated via a transformation. Of the 66 explanations in which an analogy was involved, 61 were of that generation method whereas the remaining five cases were analogies generated via an association. In the former case, students appeared to generate the analogy by simply focusing on one element of this situation. This element was the ice cube melting in a glass of water. They changed this element of the situation presented to them, they self-generated an analogous case and they applied the findings/conclusions from the latter to the former. The following three responses in the questionnaire scripts of three different aged students attest to this:

> *The A is the correct arrow of the level of the water in the glass because the ice cube is frozen water therefore when it will melt it will become water again and the level of water will rise. I have noticed that with whatever I drink and there are ice cubes in it. Sometimes, I drink it very quickly and the ice cubes are left on the bottom of the glass. I leave it to go and play and when I return, there is water in the glass.*
>
> (S12.3)
>
> *I believe that since the ice cube is frozen water when it will melt, the level of water in the glass will rise because it will add more water in the existing amount of water that the glass contains. I have seen that happening. Once I went to a restaurant with my family and I was given a glass of water with ice cubes. After almost 10 minutes water was almost over-flown from inside the glass and the ice cubes were not there anymore.*
>
> (S13.4)
>
> *I have answered A. When the ice cube melts the level of water will rise. Because things that are solids when they melt they become liquids, for example in a soft drink in glass in which we have added ice cubes, when they melt the level rises and I can see that because the taste is alternated. Ice cubes become liquid, they turn to water and thus it gets mixed with the soft drink.*
>
> (S15.5)

These three responses exemplify this type of explanations for option A in which an analogy was generated via transformation. In all of these responses students expressed the idea of water being added into the glass as if they were unable to 'see' that the solid mass of the ice has been removed and moreover they used an analogy to explain their idea claiming that this is what led them to their prediction. As it can be clearly seen from the excerpts above, these students focused on the ice cube being melted and turning into water and they came to the conclusion that this water from the ice cube should be added in the glass.

Similar and in many cases identical explanations, were reached by the students across the five age groups that used an analogy in their explanations of option A. Irrespective of their age, the only thing students changed was the element of the liquid into which the ice cube is submerged. Instead of water, some of them mentioned an ice cube submerged in a glass of ouzo (an aperitif widely consumed in Greece), orange juice and iced coffee and they came to the same conclusion about a rise in the level of the liquid (whatever this liquid was) due to the water from the ice cube that they believed would be added into the glass.

As it is mentioned in the previous paragraphs, five analogies were involved in explanations of students who chose option A one of which was formed via association. These five students aged, 17 (n=2), 15 (n=1) and 10 (n=2), years appeared to have been led to this choice by being reminded of an analogous situation that was different in many ways from the situation presented to them. However, students were led to make the same prediction as it is the case for students that involved an analogy generated via transformation. An illustration of this generation method is shown with reference to two students' responses written on the space the questionnaire included for the explanation of the question:

> *I think that A is the correct answer to this question. Ice cube is nothing more than frozen water and if it melts, water will be added in the glass. I have observed in winter the road being full of snow and afterwards full of water and that is why I think water will be added.*
>
> (S10.6)

> *I have answered that arrow A will point at about the same level as the water level in the glass after the ice cube being melted. Ice is made of water. Thus when it melts, water is added in the glass. It is similar with what I have read about the level of the sea, if ice-bergs at the North or South pole melt the level of the sea will rise.*
>
> (S17.7)

A comparison of these excerpts with those previously discussed shows that associative analogies are fundamentally different from those produced via a transformation. The former are entirely different situations in comparison to the original problem (the novel situation) whereas the latter have more similarities to share. In addition, these two explanations (S17.7 and S10.6) are similar in terms of the generation method the analogies themselves are different.

The difference lies in the elements of the situation in which students paid more attention in order to generate their analogies. In their explanation S10.6 used the idea that water would be added into the glass because the ice cube melted. Moreover, in accordance with other students, who used a transformation analogy (e.g., S12.3 and S13.4), this student generated an analogy by focusing on a situation that also involved frozen water. Nevertheless, this student (and one more student of the same age that used a very similar analogy) changed this element with another form of frozen water, that of snow. This way, the student was reminded of another case in which snow melts and turns into water reaching the same conclusion (a rise in the level of the water in the glass after the ice cube being melted).

In contrast, S.17.7 thought of an entirely different situation, albeit they used the same idea and they focused on the same element; that of the ice cube being melted and turning into water. S17.7 and two more students, one at the same age and the other aged 15 years, claimed that were led to option A by being reminded of a situation they had heard or learnt about. This situation is related to the global warming phenomenon and more particularly to the greenhouse effect. Indeed, these students made a reference to the greenhouse effect during the group discussions. Without any doubt students misunderstood the consequences of the greenhouse effects and this might be because they combined the latter with the idea of the ice cube turning into water which should be added in the container the ice cube is found. They thought of the ice cube being analogous to the ice-bergs and the glass with water being analogous to the global sea. However, this is not the case for the ice-bergs and the potential rise of the level of the sea due to global warming (or the greenhouse effect that some students referred to). Sea levels around the world could potentially rise due to the land ice melting and flowing into the oceans rather than the ice-bergs that float into the sea.

The excerpts from students' responses offered above suggest that students' idea of water being added into the glass because the ice cube has melted is not theoretically grounded. Rather this idea seems to be based on a collection of life experiences and explanations of the physical world in which students live. It is easier to understand this idea as deriving from daily experiences like the one that S12.3 used in their explanation or that of S10.6 and S15.5 than one being a stable knowledge structure.

In the case of the response given by S13.4, it appears that this students explained the prediction by using analogies deriving from everyday life situations as well. This student, and four more students, aged 12 (n=1) and 13 (n=3) years, who reason the same way and use similar analogies used the idea of water being added but in addition they expressed one more erroneous idea. This idea was identified in the interview transcripts. Although these students used an analogy in their written responses they were asked to elaborate more on them. For example, claiming that after the ice cube had melted, water almost over-flown from inside the glass, S13.4 was asked to elaborate more on that over-flowing of the water. The student claimed that it is like the water that appears on the outside of a glass of ice cold orange juice. This reasoning is incorrect and apparently students confused the water vapours normally found in air which condense onto the surface of the glass with water having over-flowed due to water that would be added, or so they believed, after the ice cube has melted.

In contrast, other students that reasoned the same way, and used very similar analogies to that of S13.4, made the correct prediction about this situation. Table 4.4.1 shows that, 14 out of the 30 students that chose option B used an analogy in their explanations. This number represents 46% of the students who made that particular choice (the correct one) and approximately 8% of all responses. Older students performed better in terms of choosing the scientific prediction. As the Table 4.4.1 shows, students aged 10 (n=1), 12 (n=3), 13 (n=8), 15 (n=7) and 17 (n=11) years chose option B. From these students, who used an analogy in their explanations, two were in Years 4 and 6, whereas four were in each of the Years 6, 7, 9 and 11. There was a significant correlation between the use of analogies which led to a correct prediction and whether students were in primary or secondary education (chi-square with one degree of freedom=6.456, p=0.011). It should be noted here that although these secondary education students made the correct prediction, none of them provided a scientific explanation for the option chosen. They reason on the basis of analogies but contrariwise with the previously examined responses, these students were led to a correct prediction.

From these 14 cases, it was found that twelve students spontaneously generated an analogy via a transformation in order to make their prediction. The example of a student's response below illustrates explanations in which students used an analogy in an attempt to justify their prediction according to which the level of the water does not change after the ice cube has melted:

> *What I chose is option B. I can't explain why this is the correct answer but I know that this is true because I have seen that happening at my family's workplace. My father has a coffee shop. When I am quite late to serve a glass of coffee with ice to the customers, I have noticed that when it melts the level of coffee in the glass does not rise.*
>
> (S17.8)

In the above response the student did not use the idea of water being added in the glass because of the ice cube melting, nor is there any indication about a possible misunderstanding of the water drops appeared on the outside of a glass of ice cold coffee as was the case with S13.4 who explained their prediction this way. What seems to be the case is that the way that students drew on their observations of what they consider as being similar phenomena to the novel situation 4 played a key role in their reasoning. Students' daily experiences and observations enabled some of them to make the correct prediction (S17.8) whereas others were led to an incorrect one (S13.4), albeit a similar reasoning was used and the analogy generated as well as the generation method was of the same type.

The other two students who chose option B and used a spontaneously generated analogy in their explanation generated it via an association. Consider the following response from a 17-year-old student:

> *I have answered B because if the ice cube, which is already in the water, is removed, the level will drop and if we put it back it will go back to level B therefore, when it will melt the level will remain the same. I mean that the water from the ice replaces the volume it held in the glass of water. It is like the case in which space is left when we use a scoop to take out an amount of sugar from a sugar vase. When this amount is taken out the space is refilled and the level of the sugar in the vase decreases but in this case we do not take out the ice cube or the water coming from it. It melts but the water refills its space.*
>
> (S17.9)

Similar to that response was one given by a 13-year-old student (instead of sugar they referred to sand being taken out from a sandbox of their cat). In this case, these two students made the claim that they were led to choose option B by being reminded of an analogous situation in memory that was different in many ways from the situation they were presented with. However, this analogy led students to make the correct prediction as it is the case for students that involved an analogy generated via transformation. Clearly, these two students constructed their explanations by using analogies deriving from situations of their daily experiences as the majority of the students did in this novel situation.

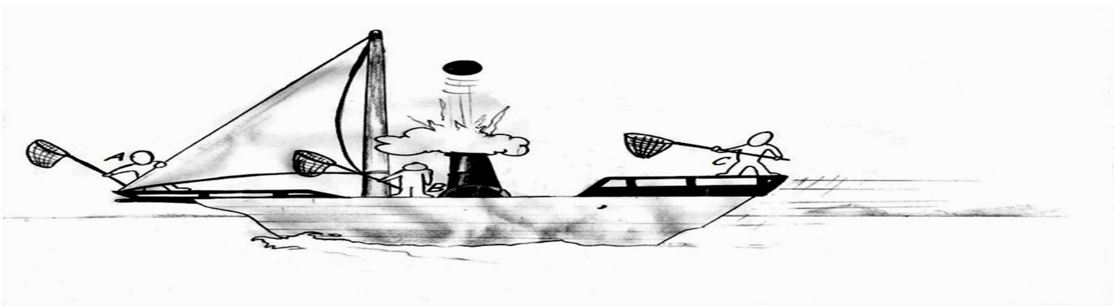
The conception of refilling empty spaces in the response provided by S17.9 could be better interpreted and understood on the basis of a p-prim identified by diSessa (1993). This is the equilibration p-prim according to which a system has a natural tendency to remain stable under certain circumstances. In the case of the present situation students claimed that as long as the ice cube or the water from it is not taken out, the system (the glass of water with the ice cube in it) should remain unchanged and thus there should not be any change in the level of the water. DiSessa argued that this phenomenological primitive might be abstracted from situations and phenomena like these that the two students used as analogies in their explanations. Moreover, the equilibration p-prim can serve as a knowledge element for the explanation of other situations like mechanics phenomena (diSessa, 1993).

Students who chose option C (9/166) did not provide an explanation about their option. Some of them neither wrote anything in their questionnaire, nor did they explain their predictions during the group discussions although they were questioned further. They used a sequence of events, explaining what happens rather than why this happens. Therefore, these responses were not analysed in terms of the explanations provided for the choice made.

From all the excerpts selected, what appears to be the case in this novel situation is that students made their prediction by drawing on their recollections of previously observed phenomena from everyday life. In most of the cases, students' conclusions were incorrect (e.g., S13.4 and S17.8) and the use of their collections of what they saw as analogous situations to this novel situation led them to incorrect predictions. In other cases (e.g., S12.3 and S10.6) students' use of analogous situations led them to correct conclusions (correct in relation to the experiences they derived from) but they misapplied (either their conclusions could not be applied in this novel situation or they applied them in an incorrect way) them and this seems to be what led them to choose the wrong option. These students (as well as the majority of the students), were led to an incorrect prediction by reasoning in the same way and by using similar analogies.

Nevertheless, there were 14 cases in which students used the same reasoning process and the same or similar analogies but they made the scientific prediction. This would suggest that even in the case of the same novel situation, similar reasoning processes and the use of the same analogies does not always lead to an incorrect prediction. In these nine cases, students' experiential knowledge was beneficial in making the scientifically correct one.

4.5 Analysis of novel situation 5: A firing cannon in a moving boat



While the ship keeps on moving at the same speed, the cannon fires a ball (as the figure shows). Which person is more likely to catch the ball?

A) Person A *B) Person B* *C) Person C*

In this subsection the analysis of the fifth novel situation is presented. As discussed in the methodology chapter, in this novel situation what is examined are students' ideas about motion. This novel situation is very similar with an example discussed in the dialogs of Galileo (Finocchiaro, 2014). Students are asked to predict which person would be more luckily to catch the cannonball. In other words, as the cannonball would be fired and while the boat would keep on moving at the same speed during the fall, students were asked to predict where the cannonball was expected to fall.

No guidance was given to the students before the completion of this particular question. The only thing that students were told is that blowing wind and air resistance should not be taken into consideration. Moreover, in some cases and for clarification purposes some of the students were told that the boat moves at a steady speed and that it moves from the right to the left as they look at the picture.

From the analysis of this novel situation in the methodology chapter (subsection 3.5.8) it was expected that students would reason that the cannonball moves upwards and as the boat continues moving, it lands behind the foot of the mast where person C stands. This is an erroneous idea and a faulty reasoning in that the cannonball falls straight down in the moving frame of the boat and the cannon (for more details read appendix F). As it discussed in the subsection 3.5.8, the cannonball starts its movement already possessing the initial forward motion of the boat and therefore, conserving that momentum it follows the forward motion of the boat (without taking into consideration the rotation of the Earth and air resistance).

Table 4.5.1 shows, as it was expected, that the most frequently selected prediction was that of option C. The vast majority of students (95%) chose option C claiming that the cannonball falls towards the rear of the boat and person C therefore is more luckily to catch it.

The analysis of students' explanations showed that most of the students followed a similar reasoning process with the one expected in that they did not take into consideration the initial forward motion of the cannonball due to the motion of the boat. Their choice of option C was explained using the idea that as long as the boat moves to the left whereas the cannonball goes upwards and downwards, the latter falls behind the cannon where person C stands. Of the 158 students that chose option C, 101 reasoned in this particular way by using in their explanations this idea.

Of those who chose option C, 51 out of the 101 merely explained their choice on the basis of the idea that as long as the boat moves horizontally and the cannonball moves vertically the latter should fall towards the back of the boat. The following two responses, representative of those given by these 51 students, illustrate the way that students explained their choice by describing how they thought about the vertical motion of the cannonball relative to the direction of the motion of the boat and clearly did not perceive the cannonball as having any horizontal motion after being fired from the cannon:

> *I have answered that person C catches the ball and this is because the boat is moving. The boat is moving to the left and the ball up and down in the air, as it will fall down it will fall at the rear part of the boat. It will be caught by person C.*
>
> (S13.1)

> *As the cannon fires the cannonball has a certain trajectory which is actually straight, it goes upwards and it falls straight back down. If the boat is steady and does not move the person in point B catches the ball. But, this boat keeps on moving forward whereas the cannonball after being fired it remains in the same position as where it was fired from the cannon. It does not move forward or backwards, it only moves upwards and downwards. So when it falls it will be going closer to the person found in the back of the boat because the boat goes forward.*
>
> (S17.2)

student's age			*prediction about the novel situation 5 (A firing cannon in a moving boat)* A) Person A	B) Person B (the correct, scientific one)	C) Person C	Total
10	involvement of analogy in the written explanation of predictions	student DID self-generate an analogy	0	0	16	16
		student DID NOT self-generate an analogy	0	0	21	21
	Total		0	0	37	37
12	involvement of analogy in the written explanation of predictions	student DID self-generate an analogy	0	0	13	13
		student DID NOT self-generate an analogy	0	0	18	18
	Total		0	0	31	31
13	involvement of analogy in the written explanation of predictions	student DID self-generate an analogy	1	0	13	14
		student DID NOT self-generate an analogy	0	0	15	15
	Total		1	0	28	29
15	involvement of analogy in the written explanation of predictions	student DID self-generate an analogy	0	2	14	16
		student DID NOT self-generate an analogy	0	1	18	19
	Total		0	3	32	35
17	involvement of analogy in the written explanation of predictions	student DID self-generate an analogy	0	3	14	17
		student DID NOT self-generate an analogy	0	1	16	17
	Total		0	4	30	34
Total	involvement of analogy in the written explanation of predictions	student DID self-generate an analogy	1	5	70	76
		student DID NOT self-generate an analogy	0	2	88	90
	Total		1	7	158	166

Table 4.5.1 Students' predictions and self-generation of analogies in novel situation 5 (A firing cannon in a moving boat)

The responses given by students S13.1 and S17.2 show that they were not able to consider the cannonball as having independent horizontal velocity because to them it is relatively stationary and so as it leaves the cannon it only moves upwards and then downwards. It appears that students tried to make a prediction by thinking about this situation like what would happen if the boat was stationary. In this case option B would be the correct one but, according to their reasoning, they then reason that as the boat is moving to the left and it would have fallen to b if the boat was stationary, then it must fall to C. The explanation of S17.2 provides more evidence about this reasoning process.

None of the students made a reference to the forces involved in this novel situation and they were not asked to do so during the group discussions as this was not the purpose of the study. Nevertheless, another possibility could be that their ideas are based on the activation of the maintaining agency or the continuous force p-prim proposed by Hammer (1996b) and diSessa (1993) respectively. This p-prim is almost identical with the maintaining agency one proposed by Hammer (1996b). Continuous force p-prim involves a constant force in order for a motion to occur. As Hammer (1996b) pointed out that this primitive might be abstracted as the individual tries to understand a continuing factor that maintains movement. For instance, an engine that makes an airplane fly. It can also be developed in an attempt to conceptualize that a supply of energy is essential in keeping a radio on or an oven ‘hot’, or even a continuous encouragement which is needed in order for a pupil to be motivated. Questions about why students think that there should be a force to maintain a motion could reveal the source for the creation of this p-prim. According to these p-prims which might be abstracted from numerous everyday experiences and phenomena there should always be a continuous and/or a constant force in order for a motion to occur. Therefore, in this novel situation, students’ ideas could be perceived as being based upon the reasoning that as long as there is not any other force acting upon the cannonball except for the one from the cannon when it fired the cannonball and/or the force of gravity, the cannonball moves. This could be what made students to think that the boat moves forward, whilst the cannonball does not thus, the ball should fall backwards.

Another possible way of explaining a faulty prediction comes from the activation of a similar p-prim. As the cannon-ball moves upwards, the dying away p-prim (all movements gradually die away) (diSessa, 1993) might have been activated. This knowledge element is in concert with the continuous force p-prim and it could be used to explain the fact that in the absence of one opposite force the cannon-ball continues going upwards in the same way like the force does (the force that the cannon exerted) until it reaches a peak in its trajectory. Dying away is abstracted from everyday life and it might not be related with kinematics and mechanics. For instance, it could be abstracted from the fading of the sound of a bell or it might be developed as students try to understand why a tossed ball returns to the ground (Hammer, 1996b). Also, it could be related with the idea that things are used up which is expected to be involved in many of the novel situations examined in this study.

The youngest students of the study sample who predicted that the cannonball falls towards person C less frequently explained their choice using the idea that the boat moves forward whereas the cannonball goes upwards and downwards and thus the latter falls astern. Of the 37 10-years-old students, 13 used this idea. Older students more frequently used this idea in order to explain their prediction (23, 22, 22, and 21 students aged 12, 13, 15, and 17 years respectively).

The difference identified in these explanations was that older students (aged 15 and 17 years) were more likely to explain their choices in terms of the motion of the boat and how the fired cannonball moves in relation to the latter. As responses showed, the difference in these students' explanations could be understood as an attempt to synthesize their naive ideas with concepts from formal instruction. Indeed, students at the age of 14 are introduced to the concept of motion as being related to a frame of reference and that an object changes its position in relation to that frame (Antoniou et al., n.d.). This concept is taught again at the age of 16 (Vlachos et al., n.d.). However, these students were not led to the scientific prediction because their reasoning process was based upon the idea that the boat moves forward whereas the cannonball goes upwards and downwards and thus the latter falls astern, albeit they used in their explanations some scientific terminology.

Of the 158 students who chose option C, 70 used an analogy in order to explain what led them to their choice. As it can be seen (Table 4.5.1) the distribution of the generation and use of analogies in students' explanations of option C is almost even among the five age-groups. There was not any association found between students' age and the use of analogies in their explanation of the prediction made (chi-square with four degrees of freedom=0.994, p=0.911).

From these 70 students, 62 spontaneously generated an analogy (their responses were coded as DSE), five self-generated an analogy as they were trying to elaborate more and explain further what led them to that particular prediction (these were coded as ISE) whereas in the remaining three cases students self-generated an analogy because they were questioned further and they were asked to provide a situation very similar with the one they were presented with (explanations were coded as PIE). A closer examination of these explanations in which an analogy was involved could also reveal what makes students understand and reason about this situation by thinking that only the boat moves forward and thus, the ball should fall towards person C.

The following three questionnaire responses show how students explained their option C choices by using an analogy. These responses show upon what circumstances or elements students focused in order to create their analogies explaining this way what led them to their choice.

> *Person C who is at the back of the boat will catch the ball. I have seen the same thing one day I went fishing with my father and some friends. I was walking with my friends and my father was following us behind. While we were walking I tossed a small ball I was holding and it went backwards and my father caught it.*
>
> (S10.3)

In the above response the student generated an analogy by changing very few elements of the firing cannon in a moving boat situation. Instead of the cannon firing the cannonball the student was reminded of an analogous case in which they tossed the ball which fell behind them. Thus, this led them to think that person C is more likely to catch the cannonball simply because this person is at the back of the boat. Contrariwise with students that merely explained their predictions by using the idea that the boat moves forward, the ball does not and thus, it should fall backwards, this student's explanation was based only upon a spontaneous self-generated analogy. From the 158 that chose option C, 21 explained that they were led to this prediction simply by using an analogy. These analogies were spontaneously created and the generation method was that of transformation.

> *I believe that when the cannon will throw the ball up, I imagine that the ball will be launched in a straight line upwards and therefore, I can say that as the ball falls and the boat moves C person will be found at the vertical downward trajectory of the ball, the ball and the person do meet. I would say that the same happens when a person is walking and he tosses a coin in the air. We will notice that the coin falls behind the person who is still walking.*
>
> (S15.4)

The above response exemplifies students' explanations in which the idea that the cannonball should fall backwards because it does not move forward whilst at the same time the boat does was combined with the use of a self-generated analogy. In accordance with the analogy in the previous excerpt the generation method in this case is that of transformation. Student S15.4 and 65 more students all across the five age groups focused on the cannonball being fired from the moving boat and by changing these two elements with another object being tossed and a person moving respectively students reasoned about this situation and they chose option C as being the correct one. The generation method of this type of analogies was evenly distributed among the five age groups.

Most of the students who chose option C reasoned in a very similar way by mentioning in their explanations the idea that the boat moves forward whereas the cannonball goes upwards and downwards and thus the latter falls backwards along with transforming the novel situation and self-generating an analogy. In addition, irrespectively of whether the explanation was of DSE or ISE type, all of the transformation analogies identified in students' explanation responses of option C were of a very similar type. The only thing that was different in these analogies was the element of the objects moving. Instead of a coin and a ball, some of the students made a reference to a pen or a basket/football ball or even a stone being tossed or thrown by a person running during a game (basketball game or other games) or walking or even sitting in a bus/ car being moving. This way, all of these 66 students followed a similar reasoning process which led them to predict that person C is more luckily to catch the ball.

> *I think that person C will catch the ball. I thought that this is very similar with something we learnt in one of the physics lessons. We were solving a problem asking to determine the point of landing for a bomb being dropped from an airplane. The answer was that it will fall directly under the airplane. This is very similar with this one but in the case with the airplane, the bomb had a high and constant speed and thus it had the tendency to continue following the direction of the airplane. Here the cannonball makes only one move, it goes up high and falls straight down. Therefore I believe that it will not fall again at point B because the ship moves forwards, the cannonball does not.*
>
> (S17.5)

Here, student S17.5 attempted to synthesise something they heard of from a physics lesson with the idea that as long as the boat moves forward and the cannonball goes upwards and downwards the latter falls astern. Focusing on the boat and the cannonball of the novel situation, as S10.3 and S15.4 did, an analogous case was generated, that of an aeroplane and a bomb. However, the analogous case generated was different from the situation presented. Student S17.5 thought of a situation in which the bomb was left to fall rather than being fired as it was the case in the novel situation. Hence, the analogous case generated is in many ways different as the bomb in student's S17.5 case moves only from the airplane to the ground whereas in the novel situation the cannonball fired in the air, goes upwards, stops at the peak of its trajectory and then it falls downwards. This way, student S17.5 was led to choose option C by being reminded of an analogous situation in memory that was different in many ways from the situation presented to them. However, this student, alongside another one of the same age and 2 more students (one aged 13 and the other aged 15) who generated an analogy via an association were similarly led to the same prediction as it is the case for students who involved an analogy generated via transformation.

In the above excerpt the student has exhibited an accurate understanding of what was taught concerning the particular example of the airplane and the bomb. Moreover, the analogy that student S17.5 generated has the potential to lead to the correct prediction despite the fact that the two situations were different in some respects. Nevertheless, the partial understanding of the analogous case generated seems to be what led student S17.5 to an incorrect prediction. The conclusion about the bomb falling direct under the airplane was not wrong but the student believed that this has to do with the high speed of the airplane. The student did not understand that this is due to the speed of the airplane irrespectively of its magnitude (if it moves slow or in a high speed) and that the bomb dropped conserves the momentum of the airplane and therefore falls straight under the latter. Therefore, student S17.5 applied this misunderstanding in the novel situation and by seeing that the analogous case and the novel situation were different in terms of the speed that the airplane and the boat moves, they came to an incorrect conclusion which made them choose option C.

The student's analogy examined above was not the only one that appeared to have the potential to facilitate the understanding of this situation and lead to the scientifically correct prediction. Other students (for example, student S10.3) from across the full age range of this study the ages used in their explanations a spontaneous analogy generated via a transformation which could potentially lead them to make the correct prediction. Another analogy of this type is shown in the questionnaire script response below:

> *I have chosen that person C will catch the ball because when the cannonball is fired it goes up high while the ship is moving and thus it falls behind where person C seats. I did the same when I was on the ferry boat one day by using my rubber as a cannonball. I tossed it up high and while the ferry boat was moving it did fall behind me. That is why I think C is the correct answer. If I had been behind where the rubber fell I would have caught my rubber.*
>
> (S12.6)

Whilst this student's analogical reasoning could have led to the scientifically correct prediction they came to an incorrect conclusion by reasoning on the basis of this analogy. The potential of this analogy generated by S12.6 is shown with reference to the following student's response. Indeed, this student reasoned on the basis of an analogy and made the correct prediction.

> *I answered that person B is more luckily to catch the cannonball. I believe that as long as the boat continues moving at the same speed the cannonball does the same and this is why it falls at the same point from which it was fired. It the same with being in a bus and we toss a pen in the air. It lands in the same in the same spot, in our arms.*
>
> (S17.7)

In the above response student S17.7 followed the same reasoning process to that of students S12.6 and S10.3. This student made a prediction by spontaneously generating an analogy; moreover, the analogy generation method was that of transformation. All of these students who generated an analogy very similar to these of students' S12.6 or S17.7 focused on the elements of the cannonball being fired from the moving boat and by changing these two elements with other objects they made their predictions. Nevertheless, they came to different conclusions and they made different predictions. In sharp contrast with the other students, this student made the correct prediction. It appears that the reason for the failure to make the correct prediction despite using similar analogies is the misapplication of the latter to the novel situation. In other words, it seems that the problem with students, who were led to an incorrect prediction, although they used a correct analogy, is that their used of the latter is misguided.

As can be seen in Table 4.5.1 only seven out of the 166 students (4% of the total sample) made the correct prediction. All of these seven students were either 15 or 17 years old. There is a significant correlation between age and response (Fisher's exact test=12.621, p=0.015). The effect size, according to Cohen's (1988) guidelines, was small to medium (Cramer's V=0.238). In the upper ages there were greater proportions of students choosing the correct option.

Of these seven students who chose the correct option, five students explained that they were led to the correct prediction by using an analogy. A statistically significant correlation was found between the use of analogies which led to a correct prediction and whether students who generated these analogies were in primary or secondary education (Fisher's exact test=8.037, p=0.033).

These students' analogies were very similar with those that younger students generated but the use of the analogy of the formers was not misguided as it was the case with the younger students (see for example, S17.7's and S12.6's response). The fact that older students performed marginally better suggests that there is an age-related development in students' achievement in terms of making the correct prediction in this novel situation. Also, the fact that five out of the seven students who made a correct prediction reasoned on the basis of an analogy would suggest that there is an age-related development in students' ability to use a correct analogy in such an efficient way that the analogy could be of crucial importance in making a correct prediction.

The reasoning processes followed by the students who used a correct analogy, but in an inefficient way, was very slightly different in that the only thing that led them to an incorrect prediction is that they came to an incorrect conclusion in the analogous case which then they applied to the novel situation. Moreover, once they generated the analogies which led them to think that the ball should fall towards the rear of the ship they held on this idea so strongly that during the group interviews they were trying to persuade other students who made the correct prediction that they were wrong. This is supported by the following students' comments in one of the group discussion settings.

> Interviewer: *Could anyone that chose option C explain what led them to their choice?*
> S15.8: *Sir, I have chosen that option and I think that the cannonball has a certain trajectory which is a straight one. It will go upwards and it will fall back down. If the ship was steady and not moving the person in B would have caught it, but as the ship is moving forward the cannonball will remain in the same position not moving forwards or backwards, it will be dangling and when it falls it will be found to be closer to the back of the boat since it will be moving forwards and the person in place C will be the one catching the ball.*
> Interviewer: *Brilliant! Could you please tell us some more about what made you think that the cannonball follows this trajectory and falls backwards?*
> S15.8: *When I saw this question I remembered of something that has happened to me. While I was running one day I tossed a stone upwards and I continued running and the stone did not return to me it fell behind me.*
> Interviewer: *Thank you for your explanation, great idea. Is anyone that thought of this question the same way?*
> [Students said yes]
> Interviewer: *Does anyone disagree with that?*

S15.9: *I do! I have chosen B and I think that the cannonball falls almost straight down like hitting the canon!*

Interviewer: *This is also a great idea! Could you please tell us why do you think your prediction is the correct one?*

S15.9: *If the boat was not moving the ball would fall on the cannon as my classmate said* [although student used their name, it is not mentioned here due to ethical issues].*But even if the boat moves, I believe that this it falls on the cannon. As when we are in the car and we throw a small ball in the air. It lands on our hands.*

S15.10: [this student agreed with student S15.8's reasoning and in their questionnaire they used a very similar analogy]. *This is not the case and I can show that* [meaning student S15.9]. *Look, if I take this piece of paper and I crumple it...Look I am walking and I am tossing it in the air... See? It lands behind* [actually students were tossing the piece of paper and then they were accelerating in order to avoid the paper landing on them].

Interviewer: *Did you notice any difference between what is said in the question and what your classmate just did?* [Silence indicating negative answer from all the students]. *Could you please do that once again?* [Student did make the same performance]

S15.9: *This is not the same, I can see that! He/she throw the paper backwards whereas here* [in the question] *the cannonball goes upwards!*

S15.11: *He/she also run faster when they tossed the paper!*

This excerpt from the interview transcription shows another example in which the same reasoning process, the same analogy generation method and a very similar analogy used led to an incorrect prediction in the first case (student S15.8) and to a correct one in the other (student S15.9). It also shows that the student S15.10 was so sure about the reasoning process that a performance was undertaken in order to convince the others. The idea was so strongly held that the student was trying to avoid the paper in order not to be hit. After the differences that student S15.9 identified in students' S15.10 performance some of the students understood in what way they were wrong but the majority of them did not agree with the claim made by the former.

When the group interviews finished, students asked about the correct options and when they were told that student S15.9 was right they were surprised. In order to explain them why that was the case, another analogy was given to them by the interviewer. Students lived in the northern part of an island which is connected with the mainland Greece via ferry boats. Therefore, students were asked to think what would have happened if they were about to toss a bottle when they are in the ferry boat. Indeed, all of them participated in this discussion agreed with the prediction made by the student S15.9 and understood the differences between the performance of student S15.10 and the novel situation they were presented with.

The latter suggests that students became dissatisfied with their idea about the cannonball falling towards the rear part of the boat because a situation arisen which required to face different perspectives from their own point of view. This way they realised what was going wrong in their reasoning process as well as the analogy they self-generated and subsequently they understood that it was necessary to change their idea and the prediction made. It could be argued that this situation proposed by the student S15.9 and the one provided by the interviewer constitute a conflict situation as it has been described by Posner Strike, Hewson and Gerzog (1982).

The following response is provided by the student who chose option A. It should be noted here that only one student out of 166 chose this option.

> *I chose A because the ship is moving leftwards and it is possible that the person at A will catch it. I chose that because when we play soccer and a player shoots the ball very high and straight the wind current which would be from the right side to the left will move the ball towards the team on the left side. Even If there is no air, maybe the ball due to its weight it might* [again] *move to the left.*
>
> (S13.12)

Although students were told that blowing wind and air resistance should be ignored, this student focusing on the cannonball being fired upwards was reminded of an entirely different situation in which wind was blowing that led them to choose option A. The generation method here was that of association as the generated analogy is different in many ways from the original situation (there is not an object moving from which another one is tossed, fired, thrown etc.). The above response and other responses in which students made a reference to games they play suggest that the manner in which students spend their time outside of school (or even during the school breaks) is reflected in the analogies they generated in order to explain this novel situation.

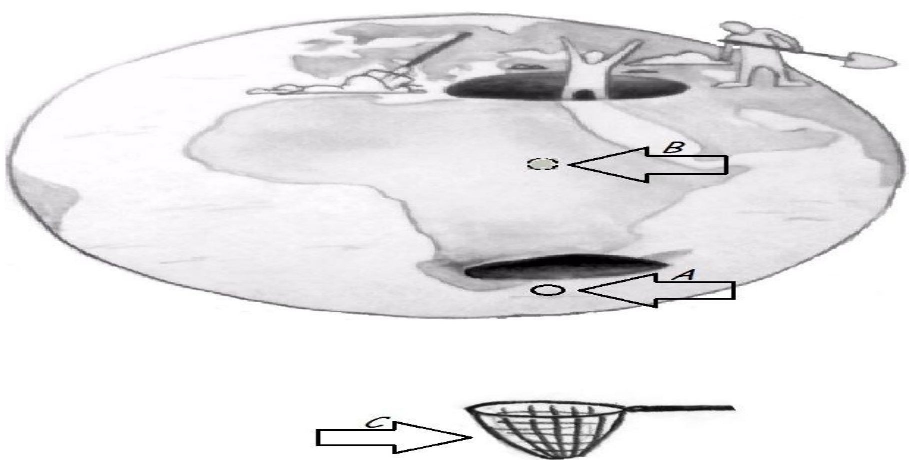
Overall, from the data analysis about this novel situation it was found that most of the students that used an analogy in their responses spontaneously generated it and they explained that this analogy was part of their thought that led them to make a particular prediction.

The vast majority of students, irrespective of their age, were led to the incorrect prediction according to which the person found in the rear part of the ship catches the cannonball. They were led to this prediction by reasoning in the same or a very similar way and in many cases they used the same analogy in their explanations. The most common generation method was that via transformation. The only difference in students' responses across the five age groups is that older students attempted to synthesize their ideas with something they have learnt in physics lessons.

Students made their predictions on the basis of their experiential knowledge and the analogies being generated attest to this. Thus, their incorrect predictions as well as the ideas expressed in their explanations could be better perceived not as being theoretically grounded but rather as being based upon phenomena they have observed in their everyday life.

However, there were some older students, who used the same reasoning process and the same analogies with students that chose an incorrect option, but they were led to the scientific prediction. In agreement with the melting an ice cube in a glass of water novel situation, this shows that although similar reasoning processes and the use of the same analogies frequently leads to an incorrect prediction, this is not the rule. The difference that one could note is on the students' analysis of the novel situation and the way they made their prediction. With the analogies generated being based upon everyday experiences, students' analysis which led to a correct prediction was based on correct literal descriptions of phenomena whereas that was not the case with students that made an incorrect prediction.

4.6 Analysis of Novel situation 6: Objects falling in holes dug into the Earth



Two people have dug a huge tunnel straight down from the one side of the Earth to the other (as shown in the figure) and one of them jumps in. Where will this person stop?

A) On the other side of the tunnel *B) In the middle of the tunnel*

C) In the net

In this subsection the analysis of the sixth novel situation is presented. This novel situation examines students' ideas about the notion of gravity and what do they mean by saying downwards and/or down. A triangulation technique of the three data sources was used in this novel situation, in order to corroborate the responses students provided in the open ended and multiple choice questions.

Some of the younger students (aged 10 years) in the pilot study claimed that as long there is lava in the centre of the Earth the person gets burnt and thus they chose option B according to which the person stops in the middle of the tunnel (the correct prediction but for fundamentally different reasons). Therefore, in the case of this novel situation, guidance was given only to the younger students who were told that they should not take into consideration the lava in the centre of the Earth. Nevertheless, as the analysis below shows, there were some students that made such a prediction by acknowledging the existence of lava. It was also made clear to the students that the hole is through the center of the Earth, and not off-center as the picture seems to suggest, albeit, there were not any issues regarding the picture in this novel situation being identified in the pilot study and, despite the fact that no student in the main study found this novel situation to be problematic in terms of presentation.

Table 4.6.1 presents how many students across the five age groups chose A, B and C options for this situation. Also, it shows the number of students who used an analogy in their responses explaining what led them to make their prediction.

It is evident from this table that the highest number of predictions was incorrect. As it can be seen, option C is the most frequently selected one. Students aged 10 and 12 years chose option C almost at the same level (the percentages was 84% in both age groups) whereas different is the case for students aged thirteen, fifteen and seventeen years (the percentages were 72%, 61% and 50% respectively). In total, 117 out of the 166 students chose option C. This represents 70% of the study sample.

student's age			prediction about the novel situation 6 (Objects falling in holes dug into the Earth) A) On the other side of the tunnel	B) In the middle of the tunnel (the correct scientific one)	C) In the net	Total
10	involvement of analogy in the written explanation of predictions	student DID self-generate an analogy	*0*	*0*	*22*	*22*
		student DID NOT self-generate an analogy	*5*	*1*	*9*	*15*
	Total		*5*	*1*	*31*	*37*
12	involvement of analogy in the written explanation of predictions	student DID self-generate an analogy	*0*	*0*	*10*	*10*
		student DID NOT self-generate an analogy	*5*	*0*	*16*	*21*
	Total		*5*	*0*	*26*	*31*
13	involvement of analogy in the written explanation of predictions	student DID self-generate an analogy	*2*	*0*	*12*	*14*
		student DID NOT self-generate an analogy	*4*	*2*	*9*	*15*
	Total		*6*	*2*	*21*	*29*
15	involvement of analogy in the written explanation of predictions	student DID self-generate an analogy	*3*	*0*	*13*	*16*
		student DID NOT self-generate an analogy	*5*	*5*	*9*	*19*
	Total		*8*	*5*	*22*	*35*
17	involvement of analogy in the written explanation of predictions	student DID self-generate an analogy	*0*	*1*	*10*	*11*
		student DID NOT self-generate an analogy	*6*	*10*	*7*	*23*
	Total		*6*	*11*	*17*	*34*
Total	involvement of analogy in the written explanation of predictions	student DID self-generate an analogy	*5*	*1*	*67*	*73*
		student DID NOT self-generate an analogy	*25*	*18*	*50*	*93*
	Total		*30*	*19*	*117*	*166*

Table 4.6.1 Students' predictions and self-generation of analogies in novel situation 6 (Objects falling in holes dug into the Earth).

Whilst the selection of option A is almost evenly distributed across the five age groups, there appears to be a progression in students' ability to make the correct prediction as they get older. Almost all the students in primary education perceived option B as incorrect. Only one student aged 10 years chose B but the prediction was explained in terms of the lava in the centre of the Earth and the explanation given was very similar with the incorrect explanation described above. Contrariwise, students in secondary education who chose the correct prediction gave an accurate explanation by using their scientific knowledge. According to the data, as children get older they seem to use their ideas and knowledge in such a way that enables them to make the scientific prediction.

The statistical analysis of the data confirms this progression in students' ability to choose the correct prediction. According to the tests used, there is a significant association between age and the prediction made, according to which in the lower ages there was a smaller proportion of students' choosing the correct option (Fisher's exact test=22.198, p=0.001). The effect size is moderate according to Cohen's (1988) guidelines (Cramer's V=0.275).

The analysis of students' explanations responses showed that students who did not choose the correct option followed a very similar reasoning process and had a similar understanding of what is meant by the words 'downwards' and 'down' irrespective of their age.

The basic idea guiding students' explanations of option C was simply that the person falls down without relating downwards direction to the centre of the Earth. This way, students' believed that the person falls in the net. Similar findings have previously been reported with the same topic and similar age groups (see for example, Mali & Howe, 1979; Sneider & Pulos, 1983; Vosniadou & Brewer, 1990) (for a more detailed discussion, see subsection 3.5.4). These studies showed that students aged between eight to 13 years hold an absolute view of down without relating it to a direction towards the centre of the Earth. In the present study, even some older students aged 15 and 17 years seemed to be holding an absolute view of down and this could be what led them to predict that the person falls in the net.

Baxter (1989) argued that students' difficulty in interpreting the meaning of downwards in terms of the centre of the Earth is related with the ideas that students hold about the shape of the Earth. This might be the case for the younger students of the present study and could explain their incorrect predictions about this novel situation. Attributing older students' incorrect prediction to their ideas of the shape of the Earth is open to doubt. It is very unlikely that students' aged 15 and 17 years hold a view of the shape of the Earth different from that of a sphere. On the contrary there is evidence according to which students aged 14 years and over are able to express and understand the scientific view for the shape of the Earth. For example, in Nussbaum's (1979) and Nussbaum's and Sharoni-Dagan's (1983) studies, students' demonstrated that people live in a spherical planet with space all around it. In any case, students in the present study were presented with a spherical Earth and thus it is plausible to assume that what led them to an incorrect prediction is not the shape of the Earth. It could be argued that the younger students, even if they were presented with a spherical Earth, were still holding a different idea about its shape (for example, a flat or a hemispherical one). However, this was not reflected in their explanation responses. An examination of the responses that students' provided in order to explain what led them to make their prediction could reveal their choice of option C.

As the data in table above show, more than half of the students (67/118) who chose option C explained that they were led to make this choice by using an analogy. There was not an association found between the age of students and whether they used an analogy in their explanations (chi square with four degrees of freedom=8.094, p=0.088). Almost equal percentages of students aged 12, 13, 15 and 17 years explained their choice by using an analogy whereas 10-year-old students more frequently based their explanation on an analogy. Grouping together all the other age groups and comparing them with the 10-year-old students' frequency in using an analogy to explain what led them to their prediction, a statistical significant difference was found (Chi-square with one degree of freedom=6.735, p=0.009). This could be interpreted as a tendency of the youngest students to reason on the basis of an analogy more frequently than the other students in order to make a prediction for this novel situation.

The analogies students used, all across the five age groups, were not only the same in terms of the generation method but they were very similar in terms of the situation students focused on in order to generate the analogous case. Consider the following three explanation responses in the questionnaire scripts of three students of different ages:

> *I have answered that the person falls in the net. Because the hole is in a straight line without any turns and therefore it will fall down, in the net. I had dug a hole of two sides and the object that I threw in came at the other end.*
>
> (S10.1)

> *My answer is that the person falls into the net. The person goes down. Because the tunnel has two holes and it is straight and thus the person ends up*

at the net. Because if you dig a hole at the beach and you pour water inside, the water will go down at the bottom.

(S13.2)

I believe that the person will stop in the net, because the tunnel is vertical and has no obstacles. Thus, when he will fall, he will stop in the net, which is located right beneath the tunnel in which he jumped in. Like when we let a basketball ball to fall in the nets. It is always the kid standing underneath the net who catches the ball, not any other kid around him.

(S15.3)

The above three responses exemplify how students of different ages explained their selection of option C by using similar analogies. All of the students, who generated an analogy similar to those in the aforementioned responses, changed very few elements of the original situation they were presented with. These analogies were coded as being generated via transformation. From the 67 analogies identified in students' explanation responses of option C, 64 were of this generation method. Moreover, all of these analogies were identified in students' questionnaire scripts and thus the explanations were coded as DSE.

Students who generated an analogy via a transformation were reminded of an analogous case in which an object was left to fall into a hole. They did not take into consideration nor make any reference to the Earth and gravity. The only thing they changed was the element of the object being left to fall into the hole as well as the type of the hole. Instead of a person and a tunnel dug into the Earth, some of the students made a reference to examples such as a stone or a ball falling and even juice being poured into a hole dug on the beach, a plastic tube and a funnel respectively. By perceiving similarities between the novel situation and the analogy they were reminded of, they simply applied the outcome from the latter to the former. According to their thinking based on those analogies whatever falls into the one end of a hole it comes out the other end and stops when the object meets an obstacle. This way, students were led to make the prediction that the person falls into the net.

From the explanations offered it is evident that many students lack of scientific understanding of gravity and gravitational attraction. Their incorrect reasoning could be explained by the absolute view of down that has been reported in other studies (discussed above) and the difficulty that students have to relate the direction of downwards in terms of being directed towards the centre of the Earth at any point on the Earth's surface. Nevertheless, another possible interpretation of their incorrect prediction could be the erroneous reasoning based on analogies which in turn were built upon the activation of a p-prim identified by (diSessa, 1993); the supporting p-prim. In the above responses it appears that students believe that as long as there is no object to physically prevent the person (like an obstacle as S15.3 stated or turns as S10.1 did) who jumped into the tunnel, the fall continues and will only stop when the person meets an object that stops them. That object, in this case, is the net and thus students made the prediction that the person continues to fall until that the fall was arrested by the net. These responses could also be explained by using a more fundamental knowledge element, the Ur-prim (Abrahams & Reiss, 2012) according to which an object will always fall downwards unless it is prevented by another object from doing so.

Additionally, it could be easier to understand this students' erroneous reasoning as being based on analogies built upon the guiding p-prim identified by (diSessa, 1993). According to this phenomenological primitive, if there is a determined path, an object directly keeps on moving along it or as diSessa put it, there are "channelled paths" that objects follow. The excerpts above attest to that. For example, S15.3 stated that the tunnel goes straight down and there are no obstacles in order for the person to stop. Thus, according to S15.3's explanation, the path should be followed until the person meets an object to stop him and this object is the net being placed underneath the other side of the tunnel.

More evidence for the activation of this p-prim was found in the explanations of three students aged 10, 12 and 13 years in which an analogy generated via an association was used. In these explanations students explained the selection of option C by being reminded of an analogous case fundamentally different with the situation they were presented with. The analogous case generated had nothing to do with a tunnel or a hole not even an object falling into something (like the net in the novel situation). An illustration of these analogies and this generation method is shown with reference to one of these three students' responses:

> *I believe the person will fall in the net and this is what I answered. Because the tunnel will not stop him, it is vertical and has no obstacles. Because it has two holes it ends up at the net. I have seen a person taking a straight road and ending up at his destination.*
>
> (S12.4)

As it can be seen in the above response, the focus on the tunnel which was straight down from the one side of the Earth to the other activated the guiding p-prim. These three students conceived the person falling into the net, having nothing to stop the fall, like a person walking on a predetermined path. Without any doubt the generated analogy is different in many ways from the original situation but led these three students to make the same prediction (the person falls into the net) as those students who generated an analogy via a transformation did.

In addition, the guiding p-prim could also explain students' prediction that the person stops on the other side of the tunnel. However, in the case of option A being chosen, students showed that they had the ability to connect downward direction with gravity. Nevertheless, their responses suggest that they understand gravitational force as being related to the Earth as a whole rather than directions towards the centre of the Earth. This was evident in an articulate response of a student aged 15 years:

> *I chose A because if we dig a hole in the ground from the one side to the other and a ball goes in it will come out on the other side, there is nothing to stop it. However the person will not fall into the space because the gravitational force that earth exerts on objects and people is the force which attracts them towards the surface of the earth. Thus, the person will end up on the other side of the tunnel however he will not fall into the net. If people leaving in the southern hemisphere like for example in Australia, would fall from the surface of the earth, these countries would have been uninhabited.*
>
> (S15.5)

The student in the above response made the prediction that as long as there is a determined path and the hole has two ends, then the person stops at the other side of the tunnel because nothing could stop the fall. Unlike students' responses mentioned above, S15.5 made a reference to gravity in order to explain why the person goes downwards. Whilst this explanation appears to be based on the activation of the guiding p-prim, it also shows that it has be influenced by the scientific theory in that student understands that is the gravity that operates in a down fashion and is responsible for people (or objects in general) from not falling from the Earth. Nevertheless, this student, as well as other students who reasoned in a similar way, was not led to the scientific prediction because the notion of 'up' and 'down' was understood relative to the surface of the Earth and not to its centre.

Of the 30 students who chose option A as being the correct one, five generated an analogy (Table 4.6.1). The reasoning and the analogies being used were very similar to that of S15.5. Making a reference to a hole and a ball (elements that were presented in the novel situation) these analogies were coded as being generated via a transformation. Also, four of these analogies were identified in students' written responses and the explanations were coded as DSE whereas the remaining one was found in the interview transcripts of 13-year-old student. The latter was coded as ISE because the student used an analogy in an attempt to explain further the first explanation given during the group discussion.

Although S15.5 made an incorrect prediction, the last part of their reasoning could potentially have led to the scientific prediction. Only one of the 17-year-old students who made the correct prediction used a very similar analogy but according to the explanation provided the reasoning was based on scientific knowledge and the analogy was generated on the basis of a formal principle. This explanation is shown in the following excerpt from the questionnaire scripts:

> *I have learnt in a physics lesson that the centre of the earth exerts force on various objects and attracts them towards it. If the person falls in the tunnel, gravitational force from the centre of the earth will not allow him to exit at points A or C and therefore he will end up in point B. Thus, the person will stop in the middle of the tunnel. It is not possible for him to stop neither on the other side nor in the net and this is like people who live in both sides of the earth. People who are located at the other side of the world, let's say in Australia, do not fall and the same happens with people who live in the upper side of the earth like Canada or North Pole. There is something in the centre that keeps them and that is why I answered B.*
>
> (S17.6)

This response clearly reveals that this student in their reasoning has the correct conception that it is the gravity that pulls objects towards the centre of the Earth. Starting from the formal principle that gravitational force is exerted towards the centre of the Earth, S17.6 generated an analogy that was even more helpful in making the correct prediction. The other students aged 13, 15 and 17 years who chose the correct and scientific prediction based their explanation merely on scientific knowledge without generating an analogy. These findings are in agreement with those reported by Baxter (1989), Nussbaum (1979) and Nussbaum and Sharoni-Dagan (1983) who found that only one out of five students aged from 14 to 16 years were holding an Earth-referenced understanding of 'down' which is not based on the Earth's surface but rather on the centre of the Earth.

Overall, the findings from this novel situation suggest that there appears to be a progression in understanding, from an absolute view of 'down' to an Earth-referenced understanding of 'downward' being related to gravitation force exerted towards the centre of the Earth. What emerged in this example was that irrespectively of their age, many students were led to an incorrect prediction by reasoning in the same or a very similar way. From the examples above, it is evident that students made their predictions on the basis of phenomena they had previously observed in their everyday life and the analogies they generated and used attest to this. However, there were students that made an incorrect prediction but they did not only use knowledge derived from their observation of the world. Their explanations showed some scientifically accurate understanding (for example S15.5) being possibly influenced from formal instruction. In sharp contrast, students who made correct predictions were found to be relying merely on their accurate scientific knowledge and their responses were very short and very similar with the first part (the first sentence) of S17.6's response.

Chapter 5

Findings of the study

5.1 Introduction

Having presented students' responses from the questionnaires and interview settings in the previous chapter, this chapter aims to review the outcomes of the data analysis by addressing each one of the four research questions set out in subsection 3.6.3 attempting at the same time to link the outcomes with the existing literature. This way, this chapter highlights the main findings of the study.

The chapter is divided into three main sections. The first section (5.2) provides a summary of what predictions, students across the five age groups, made about the six novel situations, with a greater focus on the way they made their predictions and the analogies they used. A comparison of students' reasoning about the novel situations and of the analogies they used is provided. Thus, within this first subsection the first three research questions are addressed.

The second section (5.3) looks at the ideas students' expressed in the explanations and the analogies they used to make their predictions. The focus here is on how these ideas could be understood and how they might be explained. In this section the fourth research question is addressed.

The last section (5.4) is based on the previous two sections and offers suggestions of some implications deriving from them. The focus here is on how prior knowledge and students' generated analogies could deepen, refine and extend their understanding of scientific concepts leading this way to a more effective way of teaching. Also, it proposes areas in which it might be advantageous to carry out further research in order to better understand and explain students' ideas and reasoning.

5.2 Students' predictions in the six novel situations and their reasoning: A comparison among the five age groups

This section is divided in two subsections. The first subsection presents an overview of the predictions students made across the five age groups, whilst the second addresses the reasoning behind their predictions.

5.2.1 Students' predictions

According to the findings, over 80% of the students who took part in the present study made an incorrect prediction suggesting a lack of understanding of the concepts involved in the novel situations.

In the situations involving a firing canon in a moving boat (novel situation 6) and burning wire wool (novel situation 5), the percentages were much higher with 94% of the students making an incorrect prediction. An exception to the high level of incorrect answers can be seen in case of the burning a candle situation in which case this figure dropped to only 14%.

Students across the five age groups made the predictions that might have been expected of them based on the existing literature on students' ideas about similar phenomena. For instance, the ideas students expressed about the notion of gravity in novel situations 4 and 5 are in accordance with those reported in other studies which dealt with the same notion (for example, Nussbaum's & Sharoni-Dagan's, 1983; Driver et al., 1985) with the students of the former being of similar ages to those of students in the present research.

What has also emerged is that secondary school students outperformed those of primary school on making correct and scientifically accurate predictions. In five of the novel situations (all but the burning of a candle situation), there was a statistically significant correlation between students' age and the prediction being made (see chapter 4, sections 4.2-4.6). Hence, it was noted that in lower ages there were smaller proportions of students choosing the correct prediction. The research described here is not a longitudinal study, but rather cross-age, which means that patterns of development have to be inferred across individuals. Nevertheless it is important to note that there appears to be a progression in students' ability to choose the correct answer as students get older. In some cases, those students who got the correct answer, included in their reasoning ideas that were compatible with the scientific perspective whereas other students simply selected the correct answer without showing in their explanations any scientifically correct understanding. An exception to this was found in the case of the burning wire wool situation. A large majority of students (144/166) made the incorrect prediction, which they were expected to make, but the other students' responses were evenly distributed among the other two options provided. Only ten of the remaining students chose the correct answer whereas the other 12 students chose the third option offered. Although, there was a statistically significant correlation found between the options students chose and their age, this association could not be attributed to greater proportions of students making the correct prediction but rather to the even distribution of the responses between the two options (the correct and the other incorrect one) other than the predominant one. Moreover, none of the students who chose the correct answer provided an accurate explanation for the prediction made (see the analysis of novel situations in chapter 4). On the contrary, half of the students who chose the correct answer expressed erroneous ideas and followed a faulty reasoning process which could be assumed to have led them to the scientific prediction by chance, whereas the other five students' responses resembled descriptions rather than explanations.

In the burning iron wool situation none of the students who chose the correct answer showed any correct understanding of the situation. Due to the fact that their predictions were not supported by scientific and correct ideas, it might be argued that their reasoning was incorrect, whereas in the other four situations, there were students who did provide scientifically based explanations for their predictions. In summary what this situation revealed was that correct predictions were not always proof of correct ideas and reasoning.

Whilst these results are not surprising – students' understanding of the concepts involved in the novel situations has already been questioned in other studies showing similar results (for example, Meheut et al., 1985; Vosniadou & Brewer, 1990; BouJaoude, 1991) – this study also aimed to provide an insight to the way that students made their predictions and whether their predictions as well as their understanding of the novel situations could be perceived as being based on a common reasoning process. The following subsection summarises the findings from the group discussions/interviews and open ended questions addressing, in this way, the question of how students of different ages make predictions.

5.2.2 Students' analogical reasoning in making predictions

The results indicate that analogies were widely used in students' explanations about the predictions they made. At least four in every nine students used an analogy in all six situations in order to explain what led them to make their predictions. In some cases the percentages were much higher. For instance, in the weight and gravity novel situation, 58% of the study sample reasoned on the basis of analogies in order to make a prediction and in the melting an ice cube situation, almost half of the students followed this reasoning process.

When making predictions as well as constructing written explanations for the predictions made, the vast majority (439 out of the 466 cases in which an analogy was used) of the students who used analogical reasoning, spontaneously generated analogies without being prompted by the researcher. Similar results have also been reported in previous studies of students' use of analogies (for example, Duit, 1991; Dagher, 1995; Chiu & Lin, 2005). Without being led by the researcher students, when making their predictions, generated a suitable analogous case (the base) in order to enable them to make sense of the target (the novel situation) and this was what helped them to make their predictions.

What was found in the group discussion was that fewer students self-generated analogies in an attempt to explain further what led them to make their predictions (16 cases of this type were identified). Although these students did not spontaneously generate analogies, they showed that they reasoned in a similar way to those who did by using a more familiar situation in order to understand the novel one. Analogies were also generated by some students when prompted by the researcher but this was the exception rather than the rule. Only in 11 explanations did students generate and use analogies because they were asked to provide an analogous case which was, or would have been, helpful in making their predictions. Following Blanchette and Dunbar (2000), even when students did not spontaneously generated analogies, it can be assumed that they were active in identifying and accessing analogous situations and connecting them to the novel situation. This suggests that children were actually engaged in analogical reasoning when they were trying to solve the problem they were presented with, and the self-generated analogies were observed to play a significant role in students' reasoning in order to make their predictions. When students attempted to make predictions for the novel situations they used analogies which, as several authors have argued (Oppenheimer, 1956; Brown, 1993; Wong, 1993b), facilitated their understanding of the new problem by comparing the unknown situation to a more familiar one. In particular, research suggests that analogies allow new inferences about the target (Gentner, 1983; Kurtz Miao & Gentner, 2001) to be made. In agreement with this suggestion it appears that a common way of approaching the novel situations involved the self-generation of analogies which allowed a better understanding of those situations.

Moreover, taking into consideration that the younger students (aged 10, 12 and 13 years) were not explicitly taught any of the specific concepts involved in the six novel situations (as their teachers stated and according to their curriculum) and the fact that many of them claimed that they had never thought of such cases prior to being presented with them, the central role of the analogies in decision making can be seen. The following exchange, from an interview setting, serves as an exemplar and provides evidence about the role of the analogies in making a prediction:

> Interviewer: *Ok, the boxes are the same, their weight is the same and their dimensions are the same as well. Also we should not think that there is any wind blowing. We let the boxes fall as the question says. What do you think? Which one of the bulbs lights up first?*
> S12.4: *I have seen many times something like this! I know the answer!*
> Students: *Yes! It is the elephant that falls faster!* [General consensus in this focus group]

Interviewer: *Great, could you please tell us more about your choice? What do you mean you've seen something like this before? Have you ever thought of this before?*

S12.4: *Well, I have not seen an elephant and an ant in boxes but I have seen many times heavy objects falling really fast. Ahhhhh...I thought it but I know it is true because I have chosen A, I am sure it is right. I've seen my book falling faster from my desk than my pencil. Even if I let them fall at the same time, the book will fall faster to the ground.*

S12.1: *Me too! I have not seen this happening but I just thought of many cases with heavy objects moving really fast.*

S12.2: *Yeah! I made the same choice! I did not see something like this before and I did not see an elephant falling from a great height too, but I know that if I throw a brick with a leaf, the brick will fall faster and thus the elephant will fall faster.*

From the above discussion, it can be speculated that students have never considered such a question before and they did not have a ready-made answer. As was the case in the other six novel situations, they had no specific beliefs about the situations they were presented with– either correct or incorrect – they simply had never thought of them before being asked to do so. Also, it can be seen that, although they did not have much knowledge about the situation, it triggered an associated memory and they responded to the question by generating an analogy. The analogy helped them to think about the situation and enabled them to perceive important aspects (like the difference of mass and its relation, if there is any, to the difference in the speed of falling objects). This way, they were able to easily recall information which they subsequently drew upon when making their prediction.

It appears that the analogies function because students were familiar with the analogous case they generated and they could transfer information to the unknown target. This leads to the assertion that, even though there were not any prior thoughts, and despite students lacked the scientific knowledge (or there might be some which might not be completely developed as it was the case with the older students) which could form the base for their reasoning, analogies offered them the opportunity to make sense of the situations. This way, and by reasoning on the basis of analogies, students became more familiar with the novel situation and by applying the conclusions they reached from the target situation to the former, they made their predictions. The analogies they generated simply provided them with a situation in which they knew the answer and was meaningful for them and they thought that the same answer, or a very similar one, would also be the answer to the question of the novel situation. Although it might be argued that in some cases these instances could be considered more akin to examples, models or even metaphors these could also be seen as analogies in the sense that the novel situations in which students attempted to make a prediction and explain the latter were analogous to their stored experiential knowledge. Additionally, there are several authors who have argued that all of these different terms coexist with analogy, they are close relatives and moreover they are sometimes used interchangeably (e.g., Thomas, 2006).

This reasoning, on the basis of analogies, which is found to be a common way for approaching the novel situations in the present study, is also well documented in the literature as a process of understanding and perceiving new situations. These findings are in agreement with those reported in previous studies, albeit these were related to different age groups. For example, Clement (1988, 1989, 1998) found that the analogies undergraduate students self-generated were helpful in understanding unfamiliar phenomena and moreover he showed that many experts in technical fields use analogies when they attempt to find the solutions of physics problems they have not considered before. Wong (1993a, b) supported Clement's findings concerning undergraduate students' use of analogical reasoning in phenomena they have not considered before. While many of these aspects of analogy as a tool for understanding new situations have been documented in experts and older students, the present study, in agreement with other studies from the literature (e.g., Pauen & Wilkening, 1997; May, Hammer, & Roy, 2006), provides additional evidence that primary and secondary education students are also capable of performing analogical reasoning in order to understand new phenomena and novel situations.

The generation of analogies was evenly distributed across the five age groups and the analysis demonstrated no statistically significant correlation between students' age and the use of analogies in making predictions (for details see sections 4.2-4.6). This shows that the elementary students (aged 10-12 years) of the present study reasoned on the basis of analogies almost to the same extent as the older students did. The generation and use of analogies by elementary-age students challenges the perspectives according to which there is a developmental limitation on young students' use of analogies and that analogical reasoning is absent in children until adolescence (Kuhn, 1993; Piaget, Montangero, & Billeter, 2001). Therefore, this study shows that even young students can use analogical reasoning as has been also indicated by Brown (1989) and Goswami (1992).

Whilst the generation and use of analogies by primary and secondary students is not unusual and has been reported in some other studies (Shapiro, 1994; Eilam, 2004), this is not to say that students who took part in the current study reasoned and approached the novel situations in the same way experts and undergraduate students would use analogies in order to understand new phenomena and situations. The following subsection discusses these differences and examines the generation method of the analogies as well the issue of how students in the present study accessed the analogous cases (the base).

5.2.2.1 Generation method and access to analogies

Most of the analogies identified in the present study were generated via transformation. Only very few elements were changed in order for an analogous case to be generated. Most of the students selected as base entities situations that had similar features to the entities of the novel situation (the target) they were trying to explain. For example, a student considering the weight and gravity novel situation wrote:

> *I know for sure that the elephant goes faster! I remember once, I have taken a piece of rope and a piece of iron which is really heavier than the rope, and I climbed on a high spot and I let them fall at the same time, and I observed that the iron fell faster than the rope.*
>
> (S12.5)

The above example shows how a student selected two objects which have a big difference in their mass as a base entity arguably because for this student, these two objects appeared to have similar characteristics to the elephant and the ant not only in terms of weight but also in terms of what happens when these objects are in the state of free fall. These similarities enabled this student to use the rope and the piece of iron as well as what would happen if these two objects fell to the ground in order to make a judgement about the elephant and the ant. Only these two objects were changed in order for the analogy to be generated and that was the case with the analogies generated by the majority of the students not only in the same question (weight and gravity novel situation) but also across the other five novel situations.

Evidence for analogy generation via an equation (or a formal principle) or association occurred rarely with the latter being observed more frequently than the former. These results are in agreement with those in Clement's (1988) study. The use of analogies as well as the reasoning process of the subjects in that study was quite similar to the ones the students in the present study followed. However, there were cases in which the way students used the analogies was not similar to the use of analogies by advanced problem solvers.

Expert problem solvers who took part in Clement's study transformed the target (the original problem they were trying to solve) by changing very few elements and generated an analogous case (the base) which they subsequently used to activate additional scientific knowledge in order to help them solve the problem and provide an answer. This suggests that the function of the analogies was "provocative" (Clement, 1988, p. 563) in the sense that analogies were used to activate other previously unaccessed but useful knowledge for the solution of the problem.

In Clement's words an analogy is helpful in solving problems because "one is moving to a more familiar area one knows more about, and one may then be able to transfer part of this knowledge back to the original problem" (p.581). Thus, advanced problem solvers tend to use analogies aiming at using prior knowledge (which in many cases was scientific) and constructing this way the solution of the problem (for example, in the coiled spring problem discussed in section 2.8, some solvers thought of a bending rod, they used their scientific knowledge to come to the conclusion that a spring which is longer stretches more).

Not only was analogy generation method which students in the present study used identical to that of more advanced problem solvers in other studies (Clement 1988; Wong, 1993b) but also in many cases, its function could be regarded as equivalent to the function of the analogies the latter used in their reasoning. In agreement with the aims of analogy generation in expert problem solvers, students in the present study used analogies to access useful knowledge, understand the novel situation and make their predictions. For example, a student thinking about an object falling into a hole dug into through the Earth wrote:

> *The person falls into the net! I did not know what to answer but I think this is just like water or even juice falling through a drainer. Everything which falls, it goes downwards. There is nothing to stop it. I chose C. Because the person will reach the point up to which it* [meaning the hole] *has been dug up to and he will fall in the net.*
>
> (S13.6)

From the explanation offered, it is evident that the analogy helped this student to access knowledge which might have not been previously considered as being relevant in the novel situation. Whilst, there might not be many similarities between liquids passing through drainers and a person falling into a hole dug through the Earth, it seems that the generation of the analogy played the role of a stepping stone in accessing relevant knowledge according to which every unsupported object always falls downwards. Therefore, it appears that one of the possible aims of using an analogy is to connect the unknown situation to something more familiar which might not be the analogous case itself but could lead the student to activate familiar and relevant knowledge.

In other cases, students' analogies appears to have a more direct transfer function, as it is commonly cited in the literature (Gick & Holyoak, 1983; Spenser & Weisberg, 1986). By considering an analogous case to be close to the original problem, students extracted the commonalities between the two situations and made inferences from the base to the target. In sharp contrast with the previous case in which students, and even advanced problem solvers in other studies, used the analogy to access useful knowledge and understand the new situation, students used analogies to access already established knowledge which was then transferred directly from the analogous case to the novel situation. By changing very few elements of the target, they self-generated an analogous case and they directly applied the findings/conclusions of the latter to the novel situation in which they were asked to make a prediction.

The establishment of relations and the direct transfer of knowledge form the base to the target are made explicit by S15.7's written response given in the novel situation 5 (a firing cannon in a moving boat):

> *This reminds me of taking the ball on the rebound when we play basketball. When a player throws the basketball towards the nets and the air is blowing it will go leftwards if the air is not blowing then the ball will go to the nets. Then, the ball which is like the cannonball here in the question, never falls in the same straight line and under the basket but rather it moves to another direction. That is why the player who is situated under the basket, just like the person who is next to the cannon, never catches the ball. Even if there is no air, the basketball moves to the left or to the right. Here, I think it goes to the right. I have answered C.*
>
> (S15.7)

S15.7's quotation is evidence that while trying to understand the novel situation and answer the question, the use of analogous cases is of crucial importance even if the analogies do not lead to the activation of other, relevant to the problem, knowledge but rather are used directly to extract conclusions and make a prediction-something that also occurred with many other students (e.g., see S10.3's and S17.8's responses in the analysis of novel situations 5 and 4 respectively).

It seems that in these cases, the analogous cases were pre-existing familiar knowledge structures in memory and students activated and retrieved this knowledge because for them it was closely related to the novel situation and therefore could be used for a better understanding of the latter as well as making a prediction for it. This finding directly contrasts the argument that analogous cases are somehow invented or constructed (e.g., Clement, 1988) but rather it shows that the analogies students generated originated as a whole representation in memory and when they were asked to make a prediction they retrieved these particular cases because for them these cases were considered to be closely related to the novel situations. In other words, students accessed such particular cases that could better fit to the novel situations they were presented with.

What has been observed in both cases (direct transfer of inferences from the base to the target or use of the analogies to access other knowledge), are some aspects of experts behaviours in students' analogical reasoning. This is not to say that students are just as skilled as expert problem solvers, but rather that there appeared to be signs of expert-like behaviour in students' reasoning in terms of identifying and connecting appropriate similarities between the base and the target leading this way to the analogy generation. In agreement with other studies (Clement 1998; Lising, 2004), students across the five age groups, just like experts, were able to identify similarities between the base and target in order to facilitate their understanding of the latter which subsequently led them to their predictions.

When accessing a base domain in order to make comparisons and identify any similarities with the target situation, students were guided by the aim of solving a given problem, that of making a prediction in the novel situation, and explaining what led them to their prediction, as emphasised in other studies (e.g., Gentner 1983, 1989; Holyoak & Thagard, 1989, 1997). The identification of similarities involves mapping similarities that exist between the elements of the novel situation and the analogous case generated as described by Gentner (1983) (for a detailed discussion see literature review, subsection 2.4.1).

It is clear from this study and the quotations provided that the source of information students used to generate their analogies can be seen (for more details, see subsection 5.2.2.2 within this chapter). Students' previous life experience had a strong influence on the selection of the target situation as well as the establishment of similarities between the base and the target. Despite relying upon this common source to generate an analogy, the information they used and the similarities drawn were not always the same. Each type of similarities gave each student specific information depending on its relevance to the latter's cognitive structure. For example, some of these similarities were related to characteristics and features of the compared entities (surface similarities), while others were associated with relational and structural information (structural similarities). In this sense, surface similarities refers to mapping attributes or descriptive properties of objects like shape, size and colour whereas structural similarities concerns the matching of processes and functions between the elements that are considered to be similar.

In agreement with Wellman and Gelman (1998), students in the present study appeared to be paying attention to these two different types of similarities. In their explanations they were using analogies involving both surface similarities and structural ones. However, cases in which students tried to compare merely surface similarities of the entities failed to draw analogies. For instance, in the weight and gravity novel situation there were four cases in which the younger students (aged10 years) focused on the type of animals and their size. During the group discussions these students generated the analogy that an elephant is like a rhino (or other big and heavy animals) and the ant is similar to a bee (similar in size and weight animals) in order to think about and deal with the novel situations. So, in the access process, these students were able to identify an object attribute (size and weight of the compared entities), but this mapping of surface similarities did not advance their thinking and reasoning about the novel situation. This is because they could not see any relational information concerning the existence (if any) of a relationship between the mass and the speed of these two falling animals to the ground.

In some cases surface similarities acted as a starting point from which they went on to discover further similarities, like the connection of greater mass with faster motion. This is how they came up with an analogy which helped them to make their predictions. There were also cases in which the focus on structural similarities appeared to play an important role in guiding the activation process of the analogies. For example, in the burning a candle situation a 10-year-old student was reminded of an analogous situation in which a wet sponge is being squeezed and water is expressed. There are no obvious surface similarities between a lit candle and a wet sponge and it appears that in this case, all information was functional. However, these similarities contributed to the initial access to the analogy. The access was facilitated by this student's experiential knowledge about something flowing from these two objects and this is how the analogy was generated.

These findings challenge the claim made by Gentner (1989) according to which young students rely merely on object attributes or surface similarities when they attempt to reach solutions on the basis of analogies. Rather, it appears that in the current study, students across all the five age groups focused on both surface and functional similarities.

As Brown (1989) and Ross (1989) have argued, paying attention to descriptive properties of objects or surface similarities can lead to the discovery of similarities in the underlying structure of these objects or as Vosniadou (1989) put it, surface similarities of objects can lead to “deeper, less easily accessible properties in a complex causal/relational network” (p. 418). This is the mechanism that seems to better describe how students in the present study accessed the analogies generated.

Having as a starting point the descriptive properties, which are easily accessible (Vosniadou, 1989, Haglund, Jeppsson & Andersson, 2012), students mapped the explanatory structure that both the base and target shared, they subsequently spontaneously generated the analogies and used these as a basis for making their predictions. There are several developmental studies which support this idea. These studies have shown that similarities in object attributes can enhance the possibility of analogical reasoning (e.g., Gentner & Landers, 1985; Holyak & Koh, 1987) irrespective to the age of the person who generates the analogy because the focus on surface similarities has been found not only to enhance analogical reasoning in childhood but in adulthood as well (Ross, 1989).

Although this discussion provides a description of the students’ reasoning processes, further examination of these issues exceeds the purposes of the present study. The spontaneous and self-generated analogies students used showed that they looked for similarities between the novel situation and their prior experiential knowledge which constituted the base situations that students perceived as being similar with the novel situations and it was drawing on these that led them to make predictions. This supports the argument that in order for students to understand a new situation they should construct personal interpretation of new information by using prior knowledge (Driver & Bell, 1986). The next sub section discusses the nature of students’ prior knowledge upon which they based their predictions.

5.2.2.2 What analogies students across the five age groups used

It was observed that the basic source from which students across all five age groups selected the analogous situations was their everyday life experiences. Their analogies were drawn from their everyday lives and this existing knowledge of the world around them and how they interpreted it constituted the basic knowledge on the reasoning process of the novel situations. Simply put, new information from the new situations was related to their already familiar real-world knowledge (which from now on will be shortly referred as experiential knowledge). For example, in the weight and gravity situation students were reminded of phenomena in which they have observed heavier objects falling faster than lighter whereas in novel situation 6 (objects falling in holes dug through the Earth situation) students generated analogies in which they have observed objects falling into tubes and coming out of them. Also, it appears that the way in which students spend their time outside of school and the activities they do during this time was reflected in the topic analogies they generated. For instance, in novel situation 5 (a firing cannon in a moving boat), there were some students who were led to their predictions by being reminded of situations they experienced when they were playing football and basketball. All of these analogies were generated from topics outside science. However, there were few cases in which older students selected a science related topic from previous lessons in physics (explanation from S17.5 in the firing cannon in a moving boat situation) and even textbooks (see for example the explanation of S17.7 in ice cube in a glass situation).

There was a substantial overlap of the daily experiences selected for the analogies that students across the five age groups generated in the six novel situations. Also, not only the topics were very similar but also, as the analysis of the analogies in the previous chapter indicated, the analogies used by students across the five age groups were, in some cases, identical. Moreover, as it was discussed in the previous chapter that, irrespective of students' age, in most of the cases the analogies were generated in a similar manner via a transformation.

The only age related difference between students in primary and secondary education related to the latter's more frequent use of scientific knowledge in their analogies and the explanations of their predictions. However, as the analysis of the students' explanations showed, the analogies themselves were not different as students focused on the same similarities and selected similar topics for the analogy generation. The ideas students expressed in their explanations were very similar as well. The only difference in students' responses across the five age groups was that older students (aged 15 and 17 years) attempted to synthesize their ideas with something they had learnt or heard in physics lessons merely by involving some scientific terminology in their explanations. Even in the case of analogies generated on the basis of an equation, or a formal principle, the latter served as an intermediate step in the way of connecting the experiential knowledge with the novel situation (see for example explanation of S17.8 in the weight and gravity situation in section 4.2).

The topics that students, across the five age groups, selected when generating their analogies suggest that their interpretation of the novel situations is based on their life experiences. Therefore, students' experiential knowledge of the world would also have an impact on their prediction as long as they reasoned on the basis of analogies to understand the novel situations and make their predictions. The following subsection reviews the findings concerning whether students' reasoning on the basis of analogies was successful in terms of helping them to make the correct prediction (compatible with the scientific view).

5.2.2.3 Students' reasoning on analogies and the predictions made

As the analysis showed, at least six out of seven students who reasoned on the basis of an analogy were led to an incorrect prediction in five out of the six novel situations (the burning a candle situation is excluded). In some cases the percentages were much higher. For example in novel situation 6 (an object falling in a hole dug through the Earth) 99% of the students who used an analogy in order to make a prediction were led to an incorrect prediction whereas with the burning iron wool the percentage was only slightly less at approximately 95%.

It was also found that analogies which led to an incorrect prediction were used to the same extent by all students irrespective of their ages (see the related tables in the data analysis chapter, sections 4.2-4.6). This even distribution and the finding concerning the use of the same analogies by students across the five age groups suggests that students were, in most of the cases, led into making incorrect predictions because of their use of analogies drawn from personal and everyday experiences and that the choice of such analogies remains stable over time.

One possible reason for the failure of these analogies to lead to a correct prediction is that an analogous situation never completely and accurately describes the original situation. In this sense students either used an incorrect analogy (an analogy which was not similar to the novel situation, albeit students perceived it as being) or because the analogy was correct but students misapplied it.

For instance, in the weight and gravity situation students generated analogies of heavy objects falling faster than light objects. This analogy and the inference made are not wrong if air resistance is taken into consideration. However, in order to reason and make a correct prediction in this novel situation, air resistance should be ignored. This information was given in the questionnaire script and students were also told to ignore air resistance, but it appears that most of them did not have any prior knowledge and experience of objects falling in the absence of air resistance. Therefore, it seemed that there was nothing which completely describes the novel situation which students could use to draw upon and hence make the correct prediction.

The response given by a 17-year-old student in the novel situation 5 (firing cannon in a moving boat) constitutes another example:

> *This is like what I've seen on the Road-Runner TV series. One of the episodes showed the Coyote* [a cartoon character] *having a cannon and aiming to shoot the Road-Runner* [another cartoon character] *down. In this scene the Road-Runner was moving on a bridge. The Coyote shot with the cannon up-*

> *wards, and the cannon ball did not hit the Road-Runner, but it returned towards the Coyote falling on him. But the cannon was not moving. Here it does and thus it would fall behind.*
>
> (S17.8)

S17.8 response is evidence that although the base situation (the analogy generated) was not incorrect, it led to an incorrect prediction because the latter was misapplied. The analogous case was misapplied in the sense that it is not similar with the target situation as this student responded, as it was the case with some other students' responses in the same question (see, for example responses from S13.1 and S17.2 in chapter 4; section 4.5) without taking into consideration the independent horizontal velocity of the boat and the cannon. This way, S17.8 made a prediction by thinking about this situation like as if the boat was stationary just like the cannon used by the Coyote in the analogy generated. As a result the student was led to an incorrect prediction.

Moreover, as has already been discussed, most of the times students did not know enough about the concepts involved in the novel situations either because these concepts had not been taught or even if they had been, students did not understand them. In other words, it might be the case that these students developed their explanations and made their predictions without knowing the scientific concepts involved or their answers were based on only partially correct scientific understanding of the relevant concept involved in the novel situation. In this sense, they simply lacked appropriate background knowledge so as to understand the limitations of the analogous situation they generated and this could be another explanation for students' incorrect application of the analogy generated which subsequently led them to an incorrect prediction.

Older students (aged 15 and 17 years) who reasoned on the basis of analogies and were led to an incorrect prediction had been taught most of the concepts (like gravity, combustion, relative motion and buoyancy) that the novel situations set out to probe. Although, they used some of terms from their physics (for example, gravitational pulse) and chemistry (for example, combustion) lessons their reasoning was based primarily on their experiential knowledge was very similar to that of the younger students. The argument made in the previous paragraph is that many of them did not understand the concepts or had not learnt them and thus they did not and/or could not use them.

However, the latter could also suggest that for these students analogical reasoning on the basis of experiential knowledge in order to make a prediction was more preferable than the use of scientific knowledge. Further support for this tendency of reasoning on analogous cases from students' everyday life is provided by the fact that they were very unwilling to give up these analogies even if they were given the scientific explanation and another correct analogy which could help them to understand why their prediction was incorrect (see, for example, the exchange with S15.8 and S15.9 in the analysis of novel situation 5, section 4.5). This could be attributed to the usefulness of these analogies because they are derived from everyday life, they are well-known to the students and have been beneficial for them in the past to reason and understand numerous other phenomena.

Nevertheless this was not always the case with the older students of the present study. The comparison of the responses given from students in primary education (aged 10 and 12 years) to those given from students in secondary education (aged 13, 15 and 17 years) showed that in four out of the six novel situations (burning a candle and burning iron wool situations are excluded and discussed below) there was a statistical significant difference between age and whether students made a correct prediction. A larger proportion of students in secondary education choose the scientific prediction than in the primary school group.

According to the findings, most of these students who made a correct prediction explained that they were led to this prediction on the basis of scientific knowledge they learnt at school. This suggests that students who do not use analogies in order to understand and make predictions, but reason on the basis of scientific knowledge are statistically significantly more likely to make a correct prediction.

So far, taken together, the findings seem to suggest that students rely on analogous cases that they derive from their everyday life in order to make a prediction, because frequently they do not appear to have anything else to draw on. But this would always lead them to an incorrect prediction, unless they learn the scientific fact and reason accordingly on its basis in order to make a correct prediction. Still, this is not the case because there were some older students who reasoned on the basis of analogy and made the correct prediction in four novel situations (excluding the burning ones).

The comparison made between students in primary and secondary education revealed that in three out of these four novel situations (secondary school students) were statistically significantly more likely to make a correct prediction on the basis of an analogy. Even in the case of the fourth novel situation (objects falling in holes dug through the Earth situation) in which there was not a statistical significant difference found, the only student who used an analogy and made a correct prediction was in year 11 (secondary education).

These findings raise several issues about the use of analogies in making predictions in students of different ages. The first has to do with the question of the differences in the use of analogies from students of primary education with those of secondary and the second relates to whether it is only older students who, under certain circumstances, can reason on the basis of analogies and make a correct prediction.

Concerning the first question, the results of this study indicated two factors which seem to explain the greater achievement of older students in making correct predictions on the basis of analogies. Some of these students used very similar analogies to those used by the younger students of the study sample. For instance, during one of the group discussions, a 13-year-old student when explaining the answer they had given in the weight and gravity novel situation made the following analogy:

> *If we go up on a rooftop and throw a concrete brick and a piece of paper, the concrete brick will fall first, because it is heavier and its weight, the gravity, will pull it and it will fall faster, there is more power.*
>
> (S13.9)

This student focused on the difference of mass between the two objects and this is how the analogy was generated. Similarly, older students identified the same object attributes (size and/or mass of the compared entities), they came up with similar, and in many cases identical, analogies but they reached different conclusions. For example, in the same question a 17-year-old student wrote:

> *I think that both will fall together as there is no air resistance. It is like throwing a metal ball and a piece of paper in vacuum, in absence of air. The objects will fall simultaneously and I believe that this is because air in the atmosphere* [meaning wind] *makes the heaviest objects to fall faster because of the friction. Like paper which is thin and can be carried away by the wind. But in case there is no wind they will both fall together.*
>
> (S17.10)

Although both students made their predictions on the basis of analogous cases in which objects of different mass fall from the same height, it was the older student who was able to make the correct prediction because they had developed a better understanding of the analogous case (base) and the related scientific knowledge. This could be one factor which can explain older students' greater achievement in making the correct prediction on the basis of an analogy. It shows that older students' analogical reasoning led to a correct prediction because they had an in-depth understanding of the source domain and the related knowledge and they were able to identify the appropriate similarities between the base and the target. This corroborates Vosniadou's (1989) suggestion that the effectiveness of analogical reasoning is mostly based on an individual's knowledge, rather than their reasoning skill. To put it differently, these results suggest that students' ability to reason on the basis of analogies, which can lead to a correct prediction, develops according to the individuals' conceptual development rather than from a developmental change, as Gentner (1989) claimed. Another interpretation of the older students' greater achievement could be related to the better sense of the world students acquire through additional experience they gain from everyday phenomena they observe as they get older. The opportunity to observe more phenomena or even observe the same phenomena more times provides a richer source of analogies upon which students can draw on making this way a correct prediction. A typical example of this additional experience constitutes the explanation given by S17.8 in novel situation 4 (a melting ice cube in a glass of water situation) in which students' additional experience in working in a coffee shop and observing glasses with ice cubes led to a correct prediction. In other studies it has been also argued that students' cognitive skills and experiences change as they develop and this could change the way they interpret and use analogies (Mozzer & Justi, 2011).

An answer to the second question concerning young students' ability to reason on the basis of an analogy and make a correct prediction could be given in reference to the two situations which have been excluded from the discussion so far (burning a candle and wire wool). What can be seen from students' responses is that irrespective of their age, their reasoning process and the analogies they generated which were very similar in both situations and although they were led them into the same conclusions, their predictions were different in terms of their compatibility with the scientific point of view.

Students across the five age groups reasoned on the basis of their experiential knowledge, but in the first case (burning a candle) they were led to a correct prediction whereas in the other (burning steel wool) they made an incorrect one. Also, there was not a statistical significant difference found between students' age and whether the use of analogies led to a correct prediction in both cases. This suggests that that there could be some cases in which even young students have done their observations well and they can use this experiential knowledge in such a way leading to a correct prediction, just like some older students did in the other novel situations.

Irrespective of their age, students' experiential knowledge of burning fuels which is known to contain carbon was beneficial in understanding the burning a candle situation. In the other novel situation, the students who reasoned on the basis of analogies were led to an incorrect prediction because it appears that they could not think of anything else to draw on and thus they thought of analogous cases of carbon made materials being burnt. Even older students did not perform better in terms of the prediction. It is plausible to assume that this this is because as a student gets older it is unlikely to confront situations in which objects known to contain iron are burnt and thus, it is difficult to gain this experience to draw on.

In summary, the presented findings support the hypothesis that students, irrespective of their age, can reason on the basis of analogies in order to try to make sense of new situations. Also, there is evidence that the use of analogies is more effective when students have a deeper understanding of the analogous cases generated and that the use of analogies is more effective, in terms of whether the analogous case represents accurately the target one, as students get older. What has not been examined in the present section are the ideas students expressed in their explanations and how these could be interpreted on the basis of the analogies students used in order to make their predictions and these will be considered in the following section.

5.3 Students' ideas involved in their explanations of the predictions made

The focus in this subsection is on students' explanations. This is because students' ideas often become evident when responding to questions where they are asked to provide an explanation (Moore & Harisson, 2004). In this study, there were a number of ideas, students used in their explanations, which were inconsistent with the scientific point of view. This section discusses these ideas in terms of how they can be seen either, as what has been described in the literature as misconceptions (internally consistent, persistent and relatively stable beliefs) or as situated acts of construction involving the activation of what diSessa (1981) defined as p-prims. The purpose here is not to judge the merits of one perspective over the other, but rather, to consider which of the two perspectives provides a better means of understanding the ideas students expressed.

The section is divided, into five main subsections. In these subsections the ideas students expressed for each novel situation (both the burning candle and burning wire wool are again presented together) are discussed in terms of how the two perspectives could interpret them. Although, in the data analysis part (chapter 4), comments concerning students' ideas have been made, the aim of the following sub-sections is to review the key findings in order to address the last research question which concerns the understanding of students' ideas as misconceptions or p-prims.

5.3.1 Weight and gravity (novel situation 1)

In the written responses many of the students across all the age groups (116/166) articulated in their reasoning the idea that heavier objects fall faster than light ones. This is a common idea identified in several other studies (e.g., Hestenes, Wells, & Swackhamer, 1992; Pine, Messer, & St. John, 2001). Resembling questions with this situation were presented to various age groups, with students at the age of 7 considering heaviness as being the reason for falling (therefore a light object should drop slower than a heavier one) (Bar, Zinn, Goldmuntz, & Sneider, 1994) whereas even first year university students have been found to be holding the same or similar ideas (Gunstone & White, 1981). This was the case with the students in the present study as well.

The misconceptions perspective provides an interpretation of such reasoning. It is an erroneous idea of free fall according to which there is a stable knowledge structure which directly relates the time, speed and acceleration of a falling object with its mass. Furthermore, when students drew their analogies they selected big objects to represent the box with the elephant and smaller ones for the ant. Again, according to the misconceptions point of view, this could be attributed to a confusion of weight with size, which makes students believe that larger means heavier whereas smaller is lighter. This way, students' responses could be explained by correlating this idea with the misunderstanding of free fall and the concept of gravity implying that larger objects fall faster than small ones.

On the other hand, students' reasoning could be interpreted from diSessa's (1993) perspective as being constructed by the students in the context of the novel situation rather than their having a stable knowledge structure containing the idea that heavier object fall faster than lighter. Indeed, the fact that many students have never thought of such a novel situation before and in light of the analogies they used in their explanations suggests that this construction was based on everyday experiences.

The construction of the idea that heavier objects fall faster could be attributed to the activation of two p-prims, that of Ohm's and supporting p-prims (diSessa, 1993). The former's transition to an active case is affected by the activation of the latter, a process described by diSessa as cuing priority (for more details, see chapter 2; section 2.3). The activation of the supporting p-prim (unsupported objects fall) in this case implies that as long as the ropes are cut and the boxes are unsupported they fall, and that this motion is due to gravity. Subsequently the Ohm's p-prim is activated, according to which "the stronger the agency, the greater the effect" (Hammer, 1996b, p.104). With the agency in this case being that of weight, Ohm's p-prim implies that the heavier an object is, the faster it falls. It should be noted here that as diSessa (1993) commented, the Ohm's p-prim involves another common primitive according to which "the more x, the more y" (p.147) which could be another interpretation of students' concept that the heavier the box, the faster it moves. This interpretation is similar to the common sense rule "More A-More B" (p.217) identified by Stavy, Tsamir and Tirosh (2002), with A being, in this case, the weight of the boxes and B their falling speed.

As diSessa (1993) argued, both p-prims are abstractions from everyday experiences and can be used to understand numerous situations. The supporting p-prim might be abstracted from phenomena in which objects, placed on a table or on a rack, do not move or fall and can be used to understand related phenomena (Sherin, 2006) like this weight and gravity situation students were presented with (both boxes, being unsupported as the ropes are cut, should fall downwards). The other one could be abstracted from experiences in which, for example, the more something is pushed the farthest or fastest it moves, or even from interpersonal relations of people (diSessa, 1993) (see chapter 4; section 4.6).

Moreover, the fact that there were older students who explained what led them to their predictions on the basis of similar and, in many cases, the same experiences as those used by the younger students, could support the claim that the analogies generated might be the phenomena upon which these p-prims are abstracted. To illustrate, young students explained their predictions and their ideas by drawing on analogous cases they had observed in their daily life. They had seen objects of different mass, like a brick and a feather or an olive and an olive leaf, which were left to fall from the same height, reaching the ground in different times (the heavier being seen to reach the ground first). In the case of the brick and feather there was a hand supporting the objects and thus preventing them from falling, whereas in the other it was the tree from which the olives and the leave hung which prevented them from falling. The interpretation of this observation could be the source which provided the supporting p-prim. Also, the interpretation and the understanding of the difference in mass and the falling time could be the abstraction of the phenomenon which provided the Ohm's p-prim or even a more common knowledge element, that of "more X begets more Y" (diSessa, 1993, p.151) (the heavier, the faster) which is also reported in several other studies (Minstrell, 1991; Stavy & Tirosh, 1996; Tirosh & Stavy, 1999). Once these p-prims are established, at the age of ten (the age of the younger students of the study sample) or possibly even earlier, constitute the vocabulary through which students can interpret related situations like the novel situation. The fact that they were used by the older students as well to reason about this novel situation attests to that.

Also, it was observed that some students did not react in a similar way in this novel situation and their reasoning differed. S10.15 and S12.16 (chapter 4; subsection 4.2.1) approached differently the novel situation in order to make their prediction. In their responses they expressed the idea that the box with the ant falls faster because it is lighter. This idea contradicts the previous one (heavy objects fall faster) and it is difficult to attribute it to any misconception identified in the literature. However, there were some studies in which this idea was reported with students aged between 5-7 years stating that lighter objects are faster than heavy ones (Piaget, 1972; Bar et al., 1994). This is a conception which, according to Bar et al. (1994), could be developed from students' experiences of throwing objects of different mass.

One may also understand this idea as an act of conceiving from the activation of the spontaneous resistance p-prim identified by diSessa (1993). According to this p-prim, less resistance implies a greater result and in this case heavy or large things resist motion or in diSessa's words, "Lighter objects, of course, exert less resistance and thus allow greater result.", (diSessa, 1993, p.128) were greater result means faster motion. The resistance p-prim could be understood in this case as the reverse from the Ohm's one and it is different from the latter because, as diSessa explained, it is intrinsic to the object of some imposed effort. In other words, this is an internal characteristic of objects; they do have this tendency. It can be abstracted from numerous phenomena like the one of throwing objects mentioned above or the difficulty experienced in trying to push a heavy object.

The activation of the spontaneous resistance p-prim does not however entail that the Ohm's p-prim was not part of these students' knowledge system nor it could be said that what led these students to a different conclusion was the fact that the Ohm's p-prim was not activated. Rather, it could be argued that S10.15's and S12.6's first thoughts of this novel situation were in terms of horizontal motion without taking into consideration that the two boxes are left to fall downwards (due to gravity). This could explain their reasoning, indicating at the same time that the Ohm's p-prim took a lower cuing priority –i.e. the Ohm's p-prim could not be easily activated due to the way students considered the context of the novel situation- in comparison to the spontaneous resistance p-prim. This suggests that the way p-prims are cued differed according to students' perception of the novel situation and that the same phenomenon could be interpreted and assimilated with the activation of more than one p-prim. Therefore students' incorrect predictions and the ideas identified in their explanations could be understood as events of reasoning which was based on the activation of the aforementioned p-prims. However, the p-prims themselves are not incorrect and not always inconsistent with the scientific point of view. They led to an incorrect prediction and/or idea because their activation in the particular context of the novel situation was inappropriate or, as Smith et al. (1994) put it, these erroneous ideas might be the result of using these p-prims outside their range of logical applicability.

For example, in the case of S10.15's and S12.6's responses the activation of the spontaneous resistance p-prim could be seen as a productive line of reasoning in other situations. These students' ideas are not inconsistent with Newton's second law according to which the greater the mass of an object being accelerated, the greater the amount of force needed to accelerate it. Of course that is not to say that these two students were aware of the Newtonian reasoning, but it could be argued that their reasoning constitutes a useful starting point towards an understanding of Newtonian mechanics.

Similarly the Ohm's p-prim and the supporting one which led students to claim that heavier objects fall faster are not incorrect if they were used in a different context. For example, the former could be activated in the case of Ohm's law according to which higher applied voltage (the agent) with the same resistance often results more in current (the result). Moreover, although the reasoning on the basis of an integration of the Ohm's and supporting p-prim in this novel situation led to an incorrect prediction, it is actually correct in the case when air resistance is taken into consideration. Students' reasoning which led them to claim that there is proportionality between the weight of the boxes and their falling speed could be applied to free fall in the air but not to free fall in a vacuum (as this novel situation was all about). Even in the case of the commonly reported misconception that heavier objects fall faster, this knowledge is useful and does work if air resistance is not neglected. In fact, there were students whose explanations included the next quotation:

> *It is like a brick and a feather but it depends where we would let them fall. If we throw them in the air it is the brick that reaches the ground first. The heavier goes always faster. But if we are about to let them fall somewhere where there is no air, no resistance they will fall together.*
>
> (S17.11)

As it was discussed elsewhere within this chapter, students who made an incorrect prediction and those who made a prediction which was consistent with the scientific account connected their reasoning in this situation with reasoning based upon everyday life experiences. The analogies that they both used provide evidence. Also, it can be seen in the quote above that both referred to and applied the concept that heavier objects fall faster but their reasoning could not be seen as similar not only because they reached different conclusions but also because the students who made the correct prediction showed some expertise in their explanations in the sense that they were able to recognise the role of the air resistance. Thinking of the novel situation as a problem in which air resistance should be neglected, these students were able to make the correct prediction. As Smith et al. (1994) argued this ability of transforming one given problem into another is a key characteristic in experts' reasoning. Again, it should be stressed that this is not to say that students were as skilled as experts are, but rather that their reasoning shows some characteristics of expertise.

5.3.2 Burning a candle and wire wool (novel situations 2 and 3)

The ideas students expressed in the burning a candle and burning wire wool questions are examined here together because these two situations raised comparable issues and had interesting similarities. More than half of the students (103/166) explained their predictions in terms of a decrease in mass of the burning object. Many studies have reported this misconception with students describing the powdery residue left after the burning of a material as simply disappearing (Anderson, 1990; BouJaoude, 1991) or more often as being lighter than the original substance (Driver et al., 1985). From a misconceptions perspective, this is an incorrect idea which is connected, and can be attributed, to students' misunderstanding of the process of burning. It has been reported that many students of a similar age with those in the present study have difficulty understanding that oxygen is required for burning and they cannot understand the role of oxygen in the burning process (Anderson, 1990; Watson, Prieto, & Dillon, 1995).

Although this idea of objects becoming lighter when they are burnt can and has been described as a misconception leading to incorrect conclusions (in the case of burning iron wool situation, its weight increases when it is burnt), neither the idea, nor the derived conclusion can be perceived as incorrect when a candle is burnt, because there is in fact, a decrease in the mass of the burning candles. All of the students who expressed this idea, made a correct prediction in the burning a candle situation, but an incorrect prediction in the case of the burning wire wool. This is not to say that students who were based upon this idea and made a correct prediction had a scientifically accurate understanding of the burning process and the role of oxygen (only two 17 year-old students showed an accurate understanding in the burning a candle situation). However, their idea according to which a burning candle loses weight is not inconsistent with the scientific account.

In both situations, irrespective of the material being burnt, students expressed and based their predictions upon the same idea. This finding could be interpreted as students' ideas being stable and internally consistent, reinforcing the misconceptions perspective (Vosniadou, 2002). However, this consistency of students' ideas could be attributed to the similar contextual features of these two novel situations (the way these two novel situations were set out was purposefully made to be very similar). Other studies have shown that, students' ideas about objects being burnt are inconsistent and context dependent (Watson, Prieto & Dillon, 1997).

Although proponents of the misconceptions perspective could argue that in the case of the two students who provided an explanation compatible with the scientific view, the misconception of burning objects becoming lighter were replaced towards scientific understanding, this does not seem to be the case. These two students did not consistently apply their ideas in the burning iron wool situation as they did not acknowledge the role of oxygen in the latter case whereas they did in the other one. Their correct explanations and the ideas involved in the case of a candle burning can be described as attempts to accommodate the scientific information, i.e., the role of oxygen in burning and the consideration of the process in terms of reactants and products, with their experiential knowledge according to which objects lose weight when they are burnt. These ideas were described by Vosniadou (1994) as synthetic models. In the case of the burning a candle situation, these two sources provided compatible ideas with the wire wool it generated apparently contradictory ones and this could explain why students were led to an incorrect prediction expressing incorrect ideas in the latter case. Moreover, the fact that those students who expressed the same idea in the iron wool situation shows that students were actually still holding the idea derived from their observations and they had not understood the scientific conceptions involved in these two novel situations.

In agreement with BouJaoude's (1991) conclusion, an inference to emerge from students' responses in these two situations is that they have a fragmentary understanding of the burning process. Students spontaneously generated their explanations falling back on this idea of burning objects losing mass which was in turn based upon students' experiential knowledge and thus, it cannot be perceived as being theoretically grounded. The analogies students used attest to that (for details see chapter 4, sections 4.2-4.6). Therefore, rather than understanding it as a stable and consistent concept as the misconceptions point of view implies, it can be understood as an act of construction in response to the novel situation students were presented with.

The idea might have been constructed on the basis of fragmented pieces of knowledge (p-prims), which led to internally coherent explanations because the novel situations which triggered the activation of these knowledge elements were very similar. However, this particular theme of burning and a change in mass is not clearly and directly connected to any set of p-prims diSessa (1993) suggested. This is because the p-prims identified were almost all limited to mechanical situations and according to diSessa they are not likely to provide a full account in every single situation.

Students do not have any direct experiences and observations of reactions involving the chemical change of atoms and molecules and therefore there could not be any phenomena upon which p-prims could be abstracted. It could therefore be argued that the p-prims account might not represent a useful interpretation of the idea of burning objects becoming lighter which, according to the misconceptions perspective, is related to the misunderstanding of the burning process in terms of products and reactants. However, as Taber and García-Franco (2010) emphasised, p-prims are not domain specific but rather more general abstractions. There might be a p-prim which reflects a more fundamental intuition and is not bound within the particular context of chemistry.

In fact, this suggests that students have observed that in every process taking place there is usually something used up. For example, fuel oil is used up in heating their houses, gas is used up while travelling a long distance perhaps in their family car, or even they might have experienced tiredness after an intensive outdoor activity (feeling less energetic, which might make them think that energy is used up). All of these observations could lead to an abstraction of a p-prim according to which there is always something used up. This intuitive pattern is consistent with people's idea Millar (2005) described as "something is used up in all events and processes" which was considered by Millar to be fundamental knowledge people use to understand numerous phenomena.

It should be noted that there is a parallel here with the aforementioned p-prim and the dying away ("all motion (...) gradually dies away", p.219) one identified by diSessa (1993) the activation of which could explain the generation of the idea that a force, which creates a motion (force as mover p-prim) is being used up. Given that, the origins of the idea that there is a decrease in mass of burning objects could be seen on the basis of this abstracted intuitive pattern of something being used up. The activation of this p-prim in these two burning situations would imply that the material of the objects being burnt is used up and thus, these objects become lighter.

A range of misconceptions identified in the literature could be also explained as situated acts of construction involving the activation of this p-prim. For example, the misconception that electrons are used up inside a battery (Yang, Greenbowe & Andre, 2004) or students' idea reported by Osborne (1983) according to which electric current is used up in a circuit could be attributed to the activation of this particular p-prim. Another example constitutes the concept of energy and the misconception identified by Solomon (1983) that energy is used up (and not conserved and/or transformed from one form to another). Therefore, the activation of this p-prim does not only seem to be a plausible interpretation for the majority of students' explanations offered in these two novel situations but also it could explain the ideas provided as examples in the previous two sentences. It could be regarded as a central intuitive pattern which can be used for the understanding of students' ideas in other situations. However, future research could provide more evidence about the activation of this suggested p-prim in other, different situations. Generally speaking, although there are some attempts of using the p-prims approach to explain the origins of students' ideas in chemistry (e.g., Nakhleh, & Samarapungavan, 1999; Taber, 2008; Taber & García-Franco, 2010) this issue deserves further investigation.

5.3.3 Melting an ice cube in a glass of water (novel situation 4)

The most frequently expressed idea (73/166) in this novel situation is that as the ice cubes melts, it adds to the volume of the water in the glass and thus, the level of the water is increased. Similar questions to the one in novel situation 4 have been used in few studies. For example, in one of the questions in the TIMSS project in 1995, students in the final year of secondary education (aged between 17-18) were asked to explain what happens to the level of the water in glass in which an ice cube was melted (Angell, 2004). In this study, and in agreement with the views expressed in the present one by the17-year-old students, the most common answer given was that of a rising level in the glass (in both cases the percentages were approximately the same). However, the ideas students expressed were not similar. In the TIMSS questionnaire it was explicitly mentioned that the ice cube floats prior to melting and this could be possibly what made students explain their answers in terms of buoyancy. Therefore, from a misconceptions perspective, one may see the idea of the increasing level in the glass as a misunderstanding of Archimedes' principle. For example, the misconception that weight or mass determines whether an object floats or not (Unal & Coútu, 2005).

Although, according to the Greek curriculum, students are taught about Archimedes' principle of floating and sinking of objects in Year 8 (students tend to be aged between 13-14 years old), none of the older students explained their ideas in terms of buoyancy and related concepts. The idea, therefore, that the level of the water should increase could not be explained using the misconceptions perspective described above. Moreover, the fact that the younger students, who had not been taught about Archimedes' principle at all, still explained their predictions on the basis of the same idea (increasing level of the water) reinforces the argument about a misinterpretation of students' idea using the aforementioned misconception.

The increasing level of the water in the glass could be also be interpreted as an idea constructed at the moment from other misconceptions. In fact, past research (see, for example, Linke, & Venz, 1979; Gabel, Samuel, & Hunn, 1987; Driver et al., 1993) reported students' failure in distinguishing between mass and volume. Holding this misconception and by seeing the mass of an object into water somehow or other being related to the mass of the water displaced (Hardy, Jonen, Müller, Stern, 2006) might be what led them to generate the idea that as long as ice melts and becomes liquid water there is an amount of water which should be added in the glass. This amount causes the increase in the volume of the water in the glass.

Again, however, this idea of an increasing level could be perceived as a new misconception appearing in the particular context of melting objects (like an ice cube), in container of liquids (like water in the present situation). For example, a similar context would be the increasing level of lava wherein a rock is being placed which is actually a student's idea identified in the study by May, Hammer and Roy (2006). This would give rise to the view that misconceptions are context dependant, i.e., that they do not exist independently from the context in which they appear as has been stressed by Schoultz, Säljö and Wyndham (2001).

There is not a p-prim in the literature directly available for use in interpreting the idea of an increasing level in the glass of water. Although, as it has already been discussed above, p-prims are not limited to particular domains of knowledge (diSessa's principle of invariance), there is always a danger of making a unification of a p-prim without having extensively considered it and this what makes disessa (1993) warn that there should always be a "skeptical stance toward unification" (p.121) (what diSessa described as principle of diversity). Therefore, the absence of strong evidence about the application of a potentially predicted p-prim in explaining this idea of rising level of water on one hand and other students' ideas in different situations (which can be invented or already exist in the literature, as diSessa argued) on the other, suggests that such a unification of a p-prim would seem to be problematic.

In everyday life, students had interacted with liquid water and ice and as the analysis of their responses showed, this is what led them to the idea of an increasing level in the glass of water. The analogies students generated provide evidence. Therefore, even if there is not a p-prim that could be used to interpret this idea, the latter cannot be perceived as being theoretically grounded.

There were not major differences in the daily experiences students across the five age groups used in order to explain this idea and their predictions. Especially for the older students (aged 15 and 17 years), this appears to suggest that they confront difficulties in relating the scientific concepts learnt in school to their experiences (Oloruntegbe, Ikpe, & Kukuru, 2010) or that there might be more effective ways of teaching Archimedes' principle and related concepts. Moreover, there were two other students (aged 13 and 17 years) who were also based upon their experiential knowledge to explain their idea of refilling empty spaces. This idea is illustrated in the following response (see also S17.9's response, chapter 4; subsection 4.4):

> *I think the water stays the same. I mean the height of the water in the glass does not change because it went up when we put the ice cube in it and thus, when it melts it stays there. If I was about to take out the ice cube the water will go down. It is the same with taking out some sand from my cat's sandbox, the space left is refilled by sand and the height of the sand in the sand-*

> *box goes down but here the water from the melting ice refills the space and the water* [meaning the water level] *stays where it was when we put the ice cube in the glass.*
>
> (S13.12)

In the study conducted by Castells, Erduran and Konstantinidou (2010), a student who was asked a similar question to that in novel situation 4 followed a very similar reasoning process and gave a similar response:

> I think that the water level will stay the same, because when the ice is first added to the water, displacement takes place forcing the water level to rise. As the ice melts this would counteract the displacement, but obviously the melted water would add to the volume, therefore creating a neutral effect where the water level would stay the same. (p.57).

Although these students made the correct prediction, there is no doubt that the aforementioned explanations are not the scientifically accepted ones. However, this idea of refilling differentiates from the other ones because in this case students were able to take into consideration the volume of the water which was displaced when the ice cube was put into the glass. This way, by thinking that the volume of the water produced when the ice melts as being equal to the displaced amount, they reached the conclusion that the water level should remain the same. Thus, it should be noticed here that although such responses are not compatible with the scientific view, they involve partly correct ideas.

It is also difficult to attribute these students' idea to any misconception identified in the literature. On the other hand, this idea could be understood and explained from a p-prims perspective. All of these students' explanations and the ideas involved evoke the diSessa's (1993) p-prim of equilibration according to which "a return to equilibrium is the natural result of removing a disequilibrating influence" (p.223). In this case, the activation of this p-prim could be what made students claim that as long as the ice cube, which caused the rise in the level of the water when it was placed in the glass (the disequilibration, is not removed from the glass but it simply melted, the level of the water should not change (system is still in equilibrium). DiSessa argued that this p-prim could be applied in cases in which "if a disequilibrating weight is taken out of a pan balance, it returns to equilibrium" (p.223) and that equilibration p-prim can serve as a knowledge element for the explanation of other situations like mechanics phenomena. Moreover, as diSessa commented, it might be abstracted from situations like these that S13.12 and S17.9 used in their explanations. This seems to suggest that there are cases in which the analogies students used might be the phenomena upon which p-prims are abstracted.

So, although the latter idea (refilling empty space) students expressed could be explained on the basis of an activation of a p-prim, the other one (that of an increasing level in the glass) does not seem to correspond to any of the p-prims identified in the literature. In agreement with Taber's and García-Franco's (2010) conclusion, this shows that although the mechanism of p-prims could be used to interpret many students' ideas, there could be also some other cases in which its use might be problematic.

5.3.4 A firing cannon in a moving boat (novel situation 5)

Over the past decades, similar questions to that in the present novel situation were asked to students across a wide range of ages (McCloskey, 1983a, b; McCloskey, Washburn, & Felch, 1983; Kaiser, Proffitt, & McCloskey, 1985; Dilbert, Karaman, & Duzgun, 2009). In a slightly different context, students were asked to predict and explain where an object, which is carried by a moving body (e. g. a walking person, a moving train, an airplane) and then released (fired, dropped or thrown), would fall.

According to the responses written in the questionnaire and those expressed during the group discussion, many (101/166) students articulated the idea that cannonball should fall backwards because it is only the boat that is moving forward. Consider, for example the following response (see also those made by S17.2, S15.4 and S17.5 responses in chapter 4; section 4.5):

> *I believe that when the cannon will throw the ball up, I imagined that the ball will be launched in a straight line upwards and therefore, since the boat moves, until the ball falls, theoretically the person at the back of the ship will be found at the vertical downward trajectory of the ball.*
>
> (S15.13)

This is a common idea identified in many other studies with students of similar ages to those in the present study. For example, 10-11 years old claimed that a tennis ball which is thrown vertically upwards in a moving car falls backwards (Millar & Kragh, 1994), an idea which share similar features with the one held by 16-17 years old who were asked to predict where does a bomb dropped from an airplane land and claimed that it falls straight down (Dilbert et al., 2009). All of these ideas similarly indicate a misconception of dropped objects being perceived as falling straight down irrespective of being carried by a moving body (in this case by the boat).

Also, there was one student who claimed that wind affects the actual direction of the motion of the cannonball (S13.12's response chapter 4; section 4.2), albeit students were told not to take into consideration air resistance and that there is not any wind blowing. In this case the incorrect idea of a straight-down was combined with a reference to the effect of wind. A similar idea about the wind effect was also expressed by students between 10 and 11 years old in Millar's and Kragh's (1994) study.

Related literature (e.g., McCloskey, 1983a; McCloskey et al., 1983) suggests that this misconception results from an impetus theory of motion. Put briefly, when a force is applied on an object, a property called impetus is given to the latter which keeps the object moving until is gradually used up over time (for more information read McCloskey, 1983a; Kavanagh & Sneider, 2007). In this novel situation, the consequences of this student's belief are the following: When the cannonball is fired it receives an impetus which initially makes it move in the direction of firing (upwards). Although it is being fired from a moving boat, it does not receive any impetus towards the direction of the boat (there is not any other force acting on it) and thus it does not possess forward motion. After some of the impetus (that which made it go upwards) is used up, gravity acts on the object and makes it fall straight down to the ground while the boat has already moved forward making this way the cannonball to fall astern.

It should be noted here, that it would be difficult from students' responses, given in both settings (questionnaire and group discussions/interviews), alone to certainly argue about their ideas of the forces (even that of gravity) acting upon the cannonball (this was not the aim of this situation and moreover, due to the limited time of the group discussions, there was not such an opportunity for students to be questioned further). Given that none of the students made a reference to the forces involved, the aforementioned explanation serves as a plausible account of their idea concerning the trajectory the cannonball followed making it fall astern.

McCloskey et al. (1983) showed that this misconception of a straight down fall may come from an illusion which occurs when students observe objects being dropped from a moving body. Carried objects being dropped (for example, a tennis ball dropped by a walking person), are perceived as falling in a straight vertical path relative to the carrier (the walking person in this case sees the tennis ball falling straight down) because the latter is usually acts as a frame of reference.

Indeed, there were students who explained the idea of a straight-down fall on the basis of this moving reference frame illusion. The following response given by a 17-year-old provides evidence:

> *When you leave something to fall inside a car while the car is moving, it falls straight down it does not go forward or backwards. The same happens here. As the ball will be returning straight down the ship will have already moved forward it will cause the person at the back of the ship to catch the ball.*
>
> (S17.14)

On the other hand, there were also some students who expressed the idea of a straight down fall but they appeared to be confused about the cannonball being released from a moving ship. Thus, in order to resolve their confusion, they made their prediction by thinking about this situation like what would happen if the boat was stationary. This could be another source of the straight-down misconception. Consider for example the following response (see also response of S17.8 within the present chapter; subsection 5.2.2.3 and that of S17.2 in chapter 4; section 4.2):

> *It* [meaning the cannonball] *will go upwards and it will fall back down. I think that if the ship was not moving, it would be the person in point B more likely to catch it but the question says that the ship is moving. So, the cannonball after going up it will fall down. Meanwhile, the ship has moved forward and the person in place C will be the one to catch the cannon ball. If we toss a ball up high and we move forward fast, it will not come with us it will rather fall behind.*
>
> (S15.15)

Whatever constitutes the basis for this straight-down idea, the aforementioned responses as well as the analogies students generated in order to explain their predictions reinforces the argument made by McCloskey (1983b) and Keeports (2000). As they have argued, students develop their personal understanding of motion by being based upon ideas they acquire from observations of moving objects in their everyday life. Thus, their idea could not be seen as theoretically grounded but rather as an act of fashioning their experiential knowledge according to the contextual features of this novel situation.

In addition, as Kavanagh and Sneider (2007) stressed, there has been a shift from the view which advocates the understanding of students ideas about moving objects as a fully developed set of beliefs that could be seen as a theory (theory like), like the impetus theory McCloskey (1983a) described, to the view that students' ideas are fragmented. Indeed, several studies (for example, Maloney, 1988; Nersessian & Resnick, 1989; Finegold & Gorsky, 1991; Cooke & Breedin, 1994) which were especially devised to investigate this particular issue, came to the conclusion that there is an inconsistency in students' responses concerning the motion of objects and thus cannot be understood as theory like.

Therefore, rather than interpreting the idea of a straight down fall students in the current study expressed as a stable and coherent knowledge structure, as the misconception perspective implies, it could be alternatively understood as being constructed by the activation of a p-prim; an activation guided by the context of the novel situation. The p-prim which is activated in this case is the force as mover or the continuous force one which actually appears to be parallel to the latter. According to these p-prims, objects move only when there is a force exerted on them. Moreover, in order for the object to keep on moving the force should always act on the object; named by Hammer (1996b) as the maintaining p-prim. The activation of these p-prims in this novel situation could interpret students' ideas of a straight down fall of the cannonball in the sense that as long as there is not any force acting upon the cannonball to the left there is not any reason to move towards this direction.

However, one may argue that this interpretation is closely related to the misconception perspective described above (impetus theory according to which motion implies a force). The difference here is that p-prims are encoded at a more abstract level as Hammer (1996a, b) and diSessa (1993) argued and could also explain the inconsistency of students' ideas discussed above, because different situations of moving objects with a different context would have cued other p-prims leading to different ideas and conclusions or even, as diSessa argued, the same question differently posed might cue completely different p-prims. The finding that students across the five age groups expressed the same idea of a straight down fall (consistency of responses across different ages) could be explained by the fact that the same features in the novel situation cued the same p-prims. Another difference is that the application of the aforementioned p-prims is not limited to situations of moving objects. For example, the maintaining agency p-prim could be remembered from but also used to interpret situations such as cyclists needs to keep on working the pedals of their bicycle to move or, as Hammer commented, that there should be a turned on engine to maintain the motion of a car (more examples are given in the methodology chapter; subsection 3.5.8).

Only three of the older students explained their ideas by seeing the trajectory of the cannonball as a combination of a horizontal and vertical motion. The following response in the questionnaire scripts attest to that:

> *It will be point B because as the ship moves until the cannonball is fired having the same speed with the ship which moves leftwards. I mean the cannonball performs two moves. These are the upwards and the leftwards one because it maintains the same speed as the ship.*
>
> (S17.16)

It appears that this understanding results from formal instruction. Projectile motion and related concepts are introduced in Year 9 (students tend to be aged between 14-15 years). However, the low achievement of the older students in this question provides additional evidence to the argument mentioned within the present chapter (sub-section 5.2.2.3), that students find it difficult to relate what they are being taught to their experiences. Nevertheless, this is not to say that there is always a discrepancy between the former and the latter because in the four remaining cases in which students made a correct prediction, they merely relied on their personal experiences which were in accordance with the scientific perspective.

In summary, the most common idea students expressed in this novel situation could be correctly described using both perspectives; that of the misconceptions or that of p-prims. However, it is only the latter that, in the light of other related research, can more accurately interpret students' ideas of the cannonball falling straight down relative to the ground and thus, landing in the back of steadily moving ship.

5.3.5 Objects falling in holes dug through the Earth (novel situation 6)

Similar questions to this have been used in several other studies (see, for example, Sneider, Pulos, Freenor, Porter, & Templeton, 1986; Hayes, Goodhew, Heit, & Gillan, 2003). The prediction most frequently made in the present study (117/166) was that the person falls into the net. This prediction was based upon an absolute view of down (not an Earth-centred one). These findings are consistent with the results of past research (see for example, Mali & Howe, 1979; Sneider & Pulos, 1983; Nussbaum, 1985; Baxter, 1989; Vosniadou & Brewer, 1990) with students aged between eight to 13 years expressing the same idea of an absolute view of down, towards the scientific view of an Earth-referenced understanding of down based on the Earth's centre at the age of 16-17 (for a more detailed discussion, see chapter 4; section 4.6), an idea expressed as well by the oldest of the present study's sample.

The interpretation suggested here from the misconception perspective is that the students' idea of downwards is a consistent and stable belief closely related to the idea about the shape of the Earth and its size (Mali & Howe, 1979; Nussbaum, 1979; Vosniadou & Brewer, 1992, 1994) (please read also chapter 3; subsection 3.5.4). These studies showed that it is likely that holding an understanding of the shape of the Earth different than a spherical one (for example, a flat, semi spherical or hollow spherical one) results in relating up-down directions to the Earth as a whole and not to the centre of the Earth. Therefore the misconceptions perspective attributes the idea of the person falling into the net as a misunderstanding of the notion of gravity resulting from an erroneous belief of the shape of the Earth and vice versa.

However, as it was discussed elsewhere (chapter 4; section4.6) it is doubtful that the older students (aged 15 and 17 years) think of the Earth as being flat or even as a hollow sphere. Indeed, there is evidence which suggest that students older than 14 years hold a scientific understanding of the shape of the Earth (Nussbaum, 1979; Nussbaum & Sharoni-Dagan, 1983). Moreover, in this novel situation, students were presented with a spherical Earth and thus, even for the younger students, it cannot be argued that their idea of the person falling downwards (absolute view of down) resulted from an incorrect idea of the shape of the Earth.

On the other hand, as Vosniadou and Brewer (1992) claimed, even if young students are presented with a spherical Earth, they are still holding a different idea about its shape because there is always a difficulty in resolving the contradiction between a spherical Earth and their observations on the ground of a flat Earth. Nevertheless, even this argument seems to be disputable, because Sneider and Pulos (1983), who identified the same misconceptions of gravity and the shape of the Earth, found that the latter is not always connected to the former. In Sneider's and Pulos' study, there were students younger than 14 years old who were able to understand that the Earth is spherical but at the same time they confronted difficulties to understand why people do not fall from that sphere.

Moreover, a more recent series of studies (Nobes et al., 2003; Nobes & Panagiotaki, 2003; Siegal, Butterworth, & Newcombe, 2004) revealed not only that the idea of gravity is not always connected with that of the shape of the Earth but also there was an inconsistency found in students' responses concerning a variety of phenomena related to the Earth and gravity. Therefore, another suggestion of interpreting students' ideas about the Earth and gravity is that they are fragmented and incoherent

(Nobes et al., 2003; Siegal et al., 2004). In this sense, diSessa’s (1993) view seems to be a more plausible interpretation of students’ idea about the person falling downwards into to the net.

From diSessa's (1993) perspective, this idea can be attributed to the involvement of two p-prims in students' reasoning; the guiding and supporting p-prims. Consider for example the following response given by a student who took part in the present study:

> *I think that the other human* [meaning the person who jumps into the whole] *goes into the net. I can see it has two holes and it ends up at the net. I have seen many times a person taking a road and ending up at his home.*
>
> (S10.17)

Thinking of S10.17’s idea as a stable piece of knowledge which this student may apply consistently in other situations related to astronomical phenomena (for example, the notion of gravity or day/night cycle), and then thinking about it as a misconception seems to be problematic. Similarly, S10.17’s response cannot be considered as reflecting any kind of connection between gravity and the shape of the Earth as the misconception perspective implies. Alternatively, this student’s idea could be interpreted as involving the activation of the knowledge element diSessa (1993) called guiding p-prim. DiSessa described the schematisation of this p-prim as “a determined path directly causes an object to move along it” (p.220). This p-prim could be remembered from and used to interpret situations like a train moving along a rail track or a ball following the predetermined path of a tube. Indeed, there were students who explained their predictions on the basis of such analogous situations. For example, a 13-year-old student wrote:

> *He* [meaning the person who jumped into the tunnel] *will end up at the other side of the tunnel because for example if we have a tube underneath which we have placed a net and we throw a ball from its one side it will come out through the other side and end up in the net.*
>
> (S13.18)

Similar responses were given by other students as well (see, for example, S10.1’s and S13.2’s responses in the data analysis chapter, section 4.6). This shows not only how this p-prim constitutes the vocabulary upon which students could understand the trajectory of objects fallen into tubes but it might also constitute the phenomena which the guiding p-prim is abstracted upon.

In this novel situation, the same contextual features seem to have cued different p-prims. Other students' ideas could be considered as involving the activation of the supporting p-prim. The following response (see also S12.4's response chapter 4; section 4.6) provides evidence:

> *I have answered C. He* [meaning the person who jumped in] *will stop in the net unless the net would get ripped by the speed he will fall on it. Since the tunnel has no edges to grab on and it is empty, the person will fall on the net. He is falling and he will not be stopped by anything because there are no obstacles so that he could stop in the middle or at the other end because that side is open and vertical.*
>
> (S15.19)

Again, thinking of S15.19's response as being based upon a misunderstanding of gravity and the shape of the Earth as the misconception point of view implies raises many concerns. The idea of the person falling into the net may be alternatively understood as involving the activation of the supporting p-prim. According to diSessa (1993) "a stable underlying object keeps overlaying and touching object in place" (p.220). Therefore, this idea could be interpreted as students reasoning that as long as there is nothing to support the person (like obstacles or edges as this student mentioned), who jumped into the tunnel, continues moving till meeting the net which offers support and prevents the person from falling further, unless the net is torn thus, the person will keep on falling. As it was discussed elsewhere (data analysis chapter, section 4.6) this p-prim is parallel with a more fundamental knowledge element Abrahams and Reiss (2012) named ur-prim. According to this ur-prim "Objects need to be supported to avoid falling downwards" (p. 414).

Although the misconceptions perspective does not appear to be a reasonable account to understand students' ideas according to which the person fall downwards into the net, it can be used to understand students' ideas of the person falling at the other side of the tunnel. This is illustrated in the following response:

> *The person falls downwards and thus he will stop at the other end of the, earth there is nothing to stop him but he cannot stop in the net because there is gravity on earth while space does not have gravity causing the person to hover.*
>
> (S12.20)

S12.20's response could be an example of students showing that they possess a misconception of gravity as being related to the Earth as a whole rather than directions towards the centre of the Earth. On the other hand, it could be argued that such ideas are hybrids combining the activation of the supporting p-prim with some scientific information acquired. This student stated that there is nothing to stop the person from falling (nothing to support him) and showed some scientific understanding of gravity as being responsible for people not falling from the Earth (however the idea that there is no gravity in space is incorrect here because small amounts of gravity are everywhere).

Similarly, there were other students who predicted that the person stops at point A (idea according to which the person stops at the other side of the tunnel) and their ideas could be understood on the basis of the guiding p-prim activation combined with the scientific view that gravity keeps people on Earth by pulling them down, albeit downwards direction was not related to the centre of the Earth, and keeping them attached or connected to the Earth. For these students the predetermined path was till the other side of the tunnel because gravity does not allow the person to escape the surface of the Earth.

Correct predictions, in this novel situation, were given only by students who acquired the scientific view. These students were able to understand and implement the idea that gravitational force is exerted towards the centre of the Earth. It should be noted here that the notion of gravity is introduced in Year 8 (students tend to be aged between 13-14 years) and therefore, this could explain the higher achievement of students older than 14 years in expressing scientifically accurate ideas in comparison to younger students.

5.3.6 Misconceptions or p-prims perspective?

The suggestion made here is that both perspectives could be used for the interpretation of students' ideas expressed in these six novel situations. Nevertheless, it can be argued that applying the p-prims point of view is a more fruitful way for interpreting students' ideas in the light of other, more recent research which has supported the view of context sensitivity in students' ideas. In agreement with Hammer's (1996b) argument, context sensitivity of students' ideas could be better understood from a knowledge-in-pieces perspective rather than a misconception one. This is because it attributes the element of knowledge in each particular case whereas the former does not. For example, in the case of the weight and gravity situation in which students expressed the idea that heavier objects fall faster, the p-prims perspective does not attribute a knowledge structure concerning weight and speed of falling. Rather, there is a more abstract element of knowledge concerning the agent's effort and its result.

Additionally, as it has already been discussed, in many cases there was something correct in students incorrect responses (either the prediction was incorrect and/or the ideas used in students' reasoning). The misconceptions perspective does not analyse correct knowledge elements in students' ideas; an exception though can be found in Clement's and his colleagues' work (Brown & Clement, 1989; Clement, Brown & Zietsman, 1989; Clement, 1993) in which misconceptions were used productively towards expert understanding. For example, in the case of burning a candle situation the knowledge element according to which there is always something used up in processes is not inconsistent with the scientific account of losing weight in cases of carbon made materials being burnt. In this sense, students' misconception of a decrease in mass in the case of iron wool being burnt could be explained as simply coming from using the knowledge element of something being used up outside its range of legitimate applicability.

In this study, to a large extent ideas in students' explanations were able to be interpreted in terms of p-prims documented in the literature. There was only one case (the idea of adding water in the case of the melting ice cube in a glass) in which students' idea could not be interpreted on the basis of an abstract knowledge structure as the p-prims perspective implies. There is not any misconception identified in the literature concerning this idea either. However, as Hammer (1996b) noted, it is not reasonable to expect that all the misconceptions have been identified and thus this idea could be perceived as a new one. In a similar way though, it could be argued that there might be another, more abstract knowledge structure which is not documented in the literature yet and can be used for the interpretation of this student idea.

Therefore, the findings of the present study suggest that students did not hold stable and coherent ideas as the misconception perspectives implies but rather, as their responses showed, that they had an unstable and fragmentary knowledge which was brought forward on the basis of the contextual features of the phenomenon/situation they were trying to understand and make a prediction for. These ideas appeared not to be theoretically grounded but rather as having their origins in their early life experiences. The analogies students generated attest to that.

The results of this study indicated that the use of analogies was an important aspect in students' reasoning but a question reasonably arises here: How is the use of analogies connected with this students' fragmented knowledge? As has previously been mentioned the analogous cases students generated might constitute the phenomena upon which the p-prims are abstracted. Nevertheless, this is not to say that evidence about the schematisation of the p-prims have been found because as Solomon (1993) argued, efforts to understand how an individual combines the 'inputs' and draws upon them to construct knowledge is something that could not be empirically tested. On the other hand, many of the analogies students used are very similar and in some cases identical with the situations diSessa (1993) suggested as being the source of p-prims. A typical example constitutes S13.12's analogy of a scoop of sand taken out from a sandbox which is actually identical with the phenomenon diSessa (1993) proposed as being the source for the equilibration p-prim.

Further, staying within diSessa's framework, analogies could be seen in an entirely different way in terms of the p-prims mechanism. As diSessa (1993) argued, p-prims could come together or be used in combination with reasoning on the basis of analogies. To elaborate, p-prims are activated automatically, unconsciously and in advance of any judgement of a phenomenon/situation. This activation takes place in the cognitive system of a student in advance of any "judgement of a phenomenon falling within the scope of a particular knowledge domain" (Taber & Garcia-Franco, 2010, p.133). Once a p-prim or a set of p-prims is activated, the function of analogies is to carry those activations back to the situation which is under examination. The role of p-prims thereafter is to function for making comparisons between the base (the analogous case) and the target (the given problem). In diSessa's (1993) words, "p-prims drive the recognition of similarities between situations, and they are also the basis of judgment of similar mechanisms acting in the two situations" (p.205).

5.4 Implications for science education and suggestions for further research

Although the aim was not to develop or evaluate new instructional strategies or materials, instructional implications derived from the results can be speculated. These are based on the two major themes which have arisen from the findings of this study. The first one concerns the use of analogies in making predictions as well as the analogies themselves whereas the other appertains to the ideas students expressed in their explanations and how these could be interpreted either from a misconceptions or a p-prims perspective. The suggestions for science education concerning these two themes are discussed in two out of the three subsections of this section. The first one refers to implications related to students' analogical reasoning and the second one deals with the differences in using the misconceptions or the p-prims point of view in order to identify students' ideas and follow the appropriate teaching approach. The limitations of this study are discussed in the third subsection along with suggestions for future research which would attest to the findings and even further the discoveries in this area of students' reasoning and ideas.

5.4.1 Use of analogies in science teaching

As mentioned elsewhere, analogies are well recognized as having a central role in learning science. Studies in analogical reasoning have shown that analogies provided to the students (either by their teacher, a researcher or even written in science textbooks) support and facilitate the learning of concepts at all ages and in a variety of science topics (Gentner, 1983; Brown, 1989; Glynn, 1994; Dagher, 1995, 1998). Whilst such a didactic use of analogies is a powerful instructional tool, echoing May et al. (2006) and Duit (1991), this study suggests that the use of analogies could be utilized more in education and should go beyond their didactic aim. Rather than merely asking students to use analogies generated by the teacher in order to facilitate conceptual understanding, the results of the present study add to the research about the utility of student-generated analogies in science education both as an instructional tactic as well as a research tool.

As the analysis of students' responses shows, in the process of making predictions about the novel situations, many of them spontaneously generate analogies to help themselves in making sense of the situations and support their explanations about what led them to their predictions. These explanations revealed that students held a variety of concepts (either these could be seen as misconceptions or interpreted from a p-prim perspective), which were inconsistent with the scientific account. This finding suggests that self-generated analogies could be used as a potential approach for the identification of students' erroneous ideas which challenge the learning of science concepts. In other words, student-generated analogies can serve as a diagnostic form of assessment revealing students' prior knowledge (Pittman, 1993; Wong, 1993b). Such assessments could provide teachers with valuable information about students' understanding and this could be the starting place for the introduction of new scientific concepts.

However, teachers not only need to be aware of students' prior knowledge (Hewson & Hewson, 1983) but they also need to better understand how their students use that prior, often experientially grounded everyday knowledge when thinking about new phenomena and situations (like the novel situations of the study). The use of analogies generated by the students can provide the teacher with an understanding of the ways in which students apply such real-world knowledge. In this respect, a better understanding of the generation, source and application of self-generated analogies could be a valuable tool in assisting teachers to address existing students' ideas which are not compatible with the scientific account. Conversely, with self-generated analogies reflecting and explaining where students' incorrect ideas stem from, they could be used in order to help teachers further in the identification of the latter.

In the present study there were cases in which students had been taught the concepts involved in the novel situations and although they did show some understanding of them they had not abandoned their prior ideas. They were holding a synthesis of understanding based on their everyday experiences and the scientific point of view. Therefore, student-generated analogies could also be used after instruction of a concept has been completed in order to assess students' understanding of the latter. As Pittman (1999) argued, the traditional way of assessing knowledge by having students compute answers and apply formulas is generally summative in nature and focus on what students know, whereas student-generated analogies could provide information about students' understanding of how and why of a concept thus revealing any persistence of students' prior knowledge. Teachers can act on these insights provided not only to assess the effectiveness of their instruction but they can also use this information to enable students develop further their scientific understanding in a way that is integrated with the latter's existing experiential knowledge. In other words, encouraging students to generate their own analogies and see why and how these contradict with the scientific view could increase conceptual understanding (Coll, France & Taylor, 2005).

The latter suggests that student-generated analogies could be used for what has been described in the literature as students' metaconceptual awareness (Tynjala, 1997; Vosniadou & Ioannides, 1998) of their beliefs or as metacognition (Beeth, 1998). This would enable students to understand the difference between the scientific concept and the one their analogies reflect using at the same time in an appropriate way the former in order to explain phenomena of their everyday life. For example, while teaching burning and combustion teachers can make these concepts more meaningful to the students by relating and connecting them to their prior knowledge and daily experiences, offering them opportunities to apply the scientific concept in a variety of situations. A similar suggestion about teaching these particular concepts was also made by BouJaoude (1992). Another example constitutes the weight and gravity novel situation in which students' self-generated analogies showed that although they were taught about the free fall of objects, they were still holding the idea that heavy objects fall faster. In this case, teachers should explain why in our daily life lighter objects are seen to fall slower explaining at the same time the role of air resistance and surface of the objects falling. Thus, in line with Cheng and Brown (2010), an important implication derived from the present study is that students should be taught how to connect their prior knowledge with the scientific concepts. Teachers could use student-generated analogies as a tool for the identification and creation of the connections between their students' prior knowledge and the concepts which are about to be taught, enabling this way effective learning (Bruner, 1986).

Similarly, the understanding of the way that students connect their prior thoughts with the new concepts which are being taught can provide teachers with an adequate basis for future instructional plans, strategies and materials. For example, such an understanding could inform the analogies teachers generate in order to promote conceptual understanding. As it has been briefly mentioned elsewhere (literature review chapter; section 2.10), teacher-generated analogies frequently fail to lead to conceptual understanding because the base is an analogous case from teachers' understanding and students cannot make the connections with the target. In accordance with Coll and Treagust (2008), the suggestion made here is that teacher generated analogies can be more effective in facilitating learning by being based in students' abilities and prior knowledge. In other words, taking into consideration what is familiar to the students could help teachers to generate analogies that fit to the formers' experience and knowledge making analogies more functional in the learning process.

Being interested and motivated is a key aspect of learning science because according to Harrison (2006), if students are not attracted either to the concept which is taught or the way is being taught, then learning will be limited. In addition, it is always the student who decides to be engaged or not in concept learning (Pintrich, Marx & Boyle, 1993). The conduction of the group discussions showed that student self-generated analogies was the source of rich discussions and that such discussions stimulated students' interest about the concepts the novel situations set out to probe. This supports the argument made by Duit (1991) according to which the use of analogies provokes students' interest in the topic being taught. Cosgrove (1995) showed that participation in small group discussions in which analogies are used could also motivate students to be involved in the teaching process and other studies have also argued that student-generated analogies can motivate students to be more actively engaged in the learning process (e.g., Wilbers & Duit, 2006; Haglund et al., 2012; Haglund & Jeppsson, 2013). Therefore in such a process, students should have the opportunity to draw their own analogies, even if they lack of knowledge about the target domain, as what happened with the younger students of the current study who were not taught of the concepts involved in the novel situations. This way, they can construct their own understanding learning this way from, and with, other students (Lundberg, 2003). Such a construction could be seen in the excerpt from the interviews transcription of novel situation 6 (chapter 4, subsection 4.5) in which students through discussion were led to the correct prediction and a scientifically correct understanding.

Nevertheless, the introduction of student-generated analogies as a more effective way of teaching is not a panacea. The use of student-generated analogies clearly not only does not solve all challenges to the teaching of science as Haglund and Jeppsson (2013) commented, but it can also be the source of other problems. Duit, Roth, Komorek and Wilbers (2001) described such a use of analogies in learning science as passing between Scylla and Charybdis in the sense that whilst student-generated analogies can be used effectively in science teaching they may also interfere with students' learning and understanding phenomena.

As several researchers have pointed out (Zook, 1991; Yerrick, Doster, Nugent, Parke & Crawley, 2003; Clark, 2006; Coll & Treagust, 2008) leaving students to self-generate analogies entails the risk of generating and reinforcing incorrect ideas. This was supported from the findings of the present study, in which many of the students reasoned on the basis of analogies and expressed ideas which were not in line with the scientific account. In most of the cases, students applied their self-generated analogies in ways that misled them in grasping the novel situations in such a way that could help them make correct predictions. Moreover, as Coll and Treagust (2008) commented, self-generated analogies may also reproduce faulty initial ideas which in turn can form the basis for further analogical reasoning which results in the development of more incorrect ideas. In line with Haglund and Jeppsson (2013), this suggests that it is not the analogies and their quality per se that could be used as a powerful instructional tool. Rather, as Heywood and Parker (1997) have argued, it is the process of generating and scrutinising self-generated analogies that can be useful and helpful in teaching science.

As Kress, Jewitt, Ogborn and Tsatsarelis (2001) and Ritchie, Aubusson and Harrison (2006) commented, an effective way for accessing students' thinking is through communication between them and their teachers on the basis of spontaneous generation of analogies by the formers. Therefore, teachers should encourage students' participation in group activities in which they would have the opportunity to generate and use their own analogies but in order to avoid the development of new incorrect ideas, the use of student generated analogies should not be done uncritical. However, guidance should be provided to the students in order for the latter not to focus too much on their idiosyncratic explanations (what their own analogies is all about) when trying to bring together their previous knowledge and understanding with new experiences (Clark, 2006). Although the role of the researcher was not that of a teacher in any sense, a particularly promising example of such guidance can be seen in the excerpt of the interview transcripts of novel situation 6 (a firing cannon in a moving boat), where a group of students by themselves and with brief input from the researcher managed to make sense of the novel situation and also found out what was wrong in their analogies and predictions. Moreover, as it has been already discussed, teachers role is of crucial importance in helping students to understand how their analogy differs from the scientific perspective and guide them towards the generation of a scientifically compatible analogy.

Such a use of analogies in group discussions and activities adhere to the resource perspective suggested by Heywood and Parker (1997) and Haglund and Jeppsson (2012) according to which student-generated analogies can be used in collaborative settings as a productive approach of the students' prior knowledge. The suggestion made here is that the engagement in such group activities should give students the opportunity to talk science (Lemke, 1990), breaking up this way the "monotony of lecture" and help students "to rest their minds, catch up and reflect" (Orgill & Bodner, 2004, p.246) allowing them thereby not only to express their ideas but more importantly to negotiate them with their classmates and their teachers. The latter should lead the discussion realising at the same time that the main objective of the student-generated analogies should not be the perfect match between the base and the target but rather, one of the main objectives should be the richness of the discussion.

Therefore, in agreement with Enghang's, Gustafsson's and Jonsson's (2009) argument, teachers should encourage the use of exploratory talk which should aim at reaching the scientific account through questioning. This suggests that there should be a dialogue developed between the students and the teacher with the latter adopting an active listening stance, reflecting more than once back to the formers. These discussions should not have the characteristics of a triadic dialogue as Lemke (1990) described it. This is a common and traditional way of conducting discussions in classrooms, where the teacher first asks a question knowing the correct answer and subsequently students provide an answer which is then evaluated by the teacher. Student-generated analogies could not be used effectively in such a dialogue. Rather, they could be better used in what Scott (1998) described as a dialogic discourse. To illustrate, teachers should use student-generated analogies in a dialogue where they pose genuine questions without knowing beforehand the answer and they pick up every student's analogy and ideas even the incorrect ones. They should then lead and continue the discourse until the concept which is about to be taught is made clearer and more plausible to the students. This is something that does not happen very often in the traditional way of teaching science.

Lastly, recommendations could be also derived for the design of curricula. With students' attempts to make predictions about novel situations being based on analogies which in turn are based on everyday experiences and reflect erroneous ideas, curricula designers should take it under consideration and make a clear distinction between scientific knowledge that is consistent with students' ideas and can be easily learned with new concepts that runs contrary to students' views. In order for the latter to be incorporated into the existing knowledge, curriculum should be developed with clear explanations and examples of erroneous beliefs that frequently lead to erroneous predictions and explanations of phenomena. In this case, curriculum designers could give examples of ideas and maybe analogies that experts have used in order to make correct predictions and understand a phenomenon. At the same time, it should be stressed why a student's ideas and/or analogy do not lead to scientific understanding whereas that of an expert does. The latter would support the claim made by Sinatra and Pintrich (2003) according to which learning should not involve only the reforming of existing knowledge but the restructuring of reasoning and ways of explaining modes as well.

5.4.2 Misconceptions or p-prims; Instructional implications

Students' ideas and whether these are understood from a p-prims or misconceptions stance could not be directly related to implications about actual teachers' interventions. However, there are some instructional implications that could be speculated from the differentiation of these two perspectives in terms of how each may influence a teacher's attempts to challenge students' incorrect ideas.

Several authors have argued (e.g., Hammer, 1996b; Özdemir & Clark, 2007) that from both perspectives, similar implications for instruction can be drawn. The misconceptions as well as the p-prims perspective acknowledge that a student comes to school with considerable knowledge and not as a blank slate which can be easily fitted with scientific concepts. Therefore, both suggest that a teacher should not only explore students' prior knowledge but also their reasoning looking at the same time for the sense behind the incorrect ideas they express. However, whether students' prior knowledge consists of many quasi-independent elements, as suggested by the p-prims perspective, or of stable and consistent theories, as the misconception perspective implies, is critical (Hammer, 1996a, b). This is because how one understands and subsequently designs the tasks for instruction is affected by the way students' knowledge and reasoning is perceived.

Most of the strategies that derive from both perspectives have their roots in Kuhn's (1962) early work and are based upon one of the most influential studies on ways to deal with students' incorrect ideas, which is the work of conceptual change theory (Posner et al., 1982). To put it briefly, conceptual change refers to the process which could lead students to change their prior to instruction ideas and viewpoints towards the scientific ones. The differentiation between the p-prims-perspective and the misconceptions one concerns the way these incorrect ideas should be addressed and whether and how students' prior knowledge can be used in the learning process.

According to the misconceptions perspective if a student's idea is stable and consistent (theory-like), it should be replaced or avoided because it interferes with the understanding of the scientific concepts. In order for the students to move from their misconceptions to the expert's appropriate conceptions, some particular conditions should be met. Students should become dissatisfied with the conceptions they already possess in order to accept the scientific ones. As Strike and Posner (1982) argued, this dissatisfaction could be achieved through the introduction of conflicting examples. Echoing Strike and Posner, Chinn and Brewer (1993) argue that such conflicting examples could lead students to completely give up their existing misconceptions and accept scientifically appropriate alternatives because these examples could not be treated on the basis of their existing misconceptions. Subsequently, students should understand that there is a need for a replacement of their ideas in order to resolve the conflicting situation. A new idea or a new framework should be then introduced which should be found by the students as plausible, intelligible and fruitful (Posner et al., 1982).

Looking therefore at conceptual change from the misconceptions stance, teachers should aim at replacing students' misconceptions with the experts' appropriate conceptions by ensuring that the aforementioned requirements would be met. However, as Hammer (1996b) pointed, such an approach offers no account of how the change occurs suggesting this way that it takes place in a radical way or as Brown (2010) described it, as a straightforward "flipping from the misconceived view to the correct view" (p.10). Even if this radical revolutionary model is successful in promoting conceptual change, Özdemir and Clark (2007) and Brown (2010) warns that the change might be limited to a number of contexts and that the new idea will not become embedded into students' knowledge system remaining this way independent of their explanations of everyday experiences. Brown's and Hammer's (2008) argument that such a change is not a quick fix but rather a gradual process which takes time and that students' ideas prior to instruction should build upon and be connected to the scientific concepts could offer an explanation of this failure.

In agreement with Brown and Hammer, several other researchers (see, for example, Smith, Blakeslee & Anderson, 1993; Smith, diSessa, & Roschelle, 1994) urged that instruction must make connections between the scientific concepts and the ideas students hold because the latter are more important for them as they are more functional and meaningful in interpreting phenomena students observe in their everyday life. On the contrary, the misconceptions perspective, although acknowledges the important role of students' prior to instruction knowledge as well as its origins in prior experiences and learning which takes place inside and outside of classrooms, it does not take into consideration how this students' prior understanding can be used productively in teaching. This account merely perceives students' ideas as being always wrong and that there is always a need for replacement. An exception in explicitly attributing a productive role of students' ideas constitutes the anchoring or bridging analogies (Brown & Clement, 1989; Clement, Brown, & Zietsman, 1989) which can be used to create connections between scientific concepts and other existing student conceptions. As Clement et al. (1989) put it, an anchoring analogy is "an intuitive knowledge structure that is in rough agreement with accepted physical theory" (p 555). In this sense, anchoring analogies could be used to make the connection if students are confident with the idea they express and could provide a correct answer in problems related to the concept they are being taught (Nelmes, 2005). Therefore, in this case teachers should use only these students' ideas which are compatible with the scientific view ruling out all the others which should be discarded or replaced in order for conceptual change to take place.

Simply erasing students' misconceptions and replacing them with the scientific concepts conflicts with the basic premise of constructivism which perceives students' ideas as a basic and primary source for learning (see also the literature review chapter, subsection 2.2). Even if it is a matter of term use, the misconceptions perspective overemphasizes the discontinuity between students' ideas and experts' concepts and it also conveys to students that their conceptions and their attempts to understand the world around them is fundamentally flawed, when in fact, as Smith et al. (1993) argued in their paper, even those students' ideas which are most robust, might be the source of productive and effective knowledge.

What has been shown in the present study is that applying the p-prims perspective (knowledge-in-pieces account) has proven to be more useful in interpreting the ideas students expressed. This epistemological stance could resolve the aforementioned conflict of the use of students' ideas. Adopting diSessa's (1988, 1993) view and looking at conceptual change from this perspective, students' alternative conceptions could serve as a basic and productive resource towards expertise. Moreover, in sharp contrast with the misconceptions perspective which does not offer details about the process of conceptual change, the knowledge-in-pieces account provides more tools which can be used to describe how the change takes place (Özdemir & Clark, 2007). For diSessa, learning involves the modification and combination of different kind of fundamental conceptual elements in such a way in order for a more organised framework to be constructed. Thus, with prior knowledge being the vehicle through which conceptual change could be achieved, the change, as a cognitive process, takes place in the mind of the students through the organisation of the existing p-prims into a more structured and coherent network (Mayer, 2002).

Understanding a student's views and ideas as an activation of knowledge elements specific to the situation presented, as the p-prims perspective implies, affects differently from the misconceptions account the way teachers should use students' prior to teaching knowledge in order for conceptual change to occur. In agreement with Clark, D'Angelo and Schleigh (2011) and as the results of the present study showed, perceiving students' knowledge as having an elemental nature suggests that teaching should focus on how, under what circumstances and in what contexts these elements are activated. Therefore, teachers should first pay attention to students' ideas and help them become aware of their central elements of knowledge. But this is not enough. Aiming at allowing students to construct a framework that they would use in a number of situations and not merely replacing their misconceptions with the scientific account with its use being limited to specific contexts, teachers should attempt to help students reorganize and reprioritize their knowledge elements and the way these are connected in their conceptual framework.

As diSessa (1993) asserts, p-prims are fundamental and useful because they are used for the description of events in the physical world in terms of students' intuitive conceptualization and understanding. As it has been already discussed the central idea of learning on the basis of the p-prims mechanism is that these knowledge elements should be cued in appropriate contexts in order for complex and stable formal knowledge to be built. In agreement with Wagner (2006), the suggestion made here is that by adopting the p-prims perspective, a teacher could be given guidance on which common intuitions they should try to avoid activating and on the other hand, which might be used productively in the teaching of particular scientific concepts. Thus, the role of teachers should be of crucial importance in providing students with the opportunity to use the p-prims in appropriate contexts and at the same time help them (teachers) understand why their activation might not be quite useful in others. The latter links back to the use of analogies in teaching discussed in the previous subsection (5.4.1).

From the same perspective implications could be derived for the design of the curriculum. Designers should also focus on students' elemental knowledge and by devising appropriate assessment tasks they should give students the opportunity to reorganise modify and reprioritize their existing knowledge. In agreement with Özdemir and Clark (2007), the suggestion made here is that this process could be based on a refinement of students' knowledge elements through the examination and confrontation of the same phenomenon in different contexts.

To sum up, from the p-prims perspective a teacher sees knowledge elements (p-prims) which could potentially contribute to the understanding of scientific knowledge; whereas from the other perspective a teacher perceives students' ideas as showing an inherent inconsistency with scientists' knowledge. The basic difference for teachers is that the latter implies the design of such tasks which should aim in avoiding or replacing any kind of prior knowledge. On the other hand, the former suggests that the tasks should help students modify the organization and the way of using prior knowledge. To illustrate the differences concerning the teaching implications which derive from the two perspectives, consider for example the idea students expressed most frequently in novel situation

5 (a firing cannon in a moving boat) and how this could be challenged either by perceiving it as a misconception or as an act of thinking about this particular situation involving at the same time the activation of a p-prim. Students' reasoning led them to predict that the ball falls behind the cannon where person C stands and this is because the boat moves to the left and the cannonball goes upwards and downwards in the meanwhile.

As it has already been discussed (subsection 5.3.4), looking at this idea from a misconceptions stance, a teacher may see students' reasoning stemming from an impetus theory of motion (McCloskey, 1983a; McCloskey et al., 1983). The practical significance adopting this perspective would be to eliminate, replace or at least weaken this impetus theory. As Hammer (1996b) argued, the primary task for a teacher would be to encourage their students to talk more about this idea in order to be sufficiently articulated. Indeed, alone from students' predictions and the responses they gave concerning what led them to make these predictions, it could not be argued that the impetus theory is made explicit. Therefore, in this particular case, a teacher should first draw out the misconception that there is not any impetus given to the cannonball towards the direction of the boat and thus, without possessing forward motion, whereas the boat keeps on moving to the left, the cannonball falls astern. Subsequently, the teacher should expand on these students' responses and also build on students' arguments which show some scientific knowledge, if there are any, presenting at the same time a series of conflicting situations which should lead students towards dissatisfaction with their existing ideas. In these conflicting situations students should not be able to dismiss, ignore, or reinterpret the situation on the basis of their existing framework and then, the new and scientific understanding of the trajectory of the cannonball should be introduced to the students in such a way that the latter would find it plausible, intelligible and fruitful. This is how the misconception would be eliminated giving its place to the scientific concept. An example of this process described here could be seen in the interview transcript of the analysis of novel situation 5 (firing cannon in a moving boat).

On the other hand, from diSessa's (1993) view, students' ideas of the cannonball falling straight down relative to the ground and thus, landing in the back of the ship could be seen as an act of construction based on a p-prim which was activated due to the particular context of this novel situation. As it was discussed elsewhere (chapter 5, subsection 5.3.4), the activation of the force as a mover and/or the continuous force p-prims (the act of setting an object in motion implies a force which is responsible for maintaining motion in general) could explain these students' ideas. In agreement with the misconceptions view, a primary task for a teacher would be to explore further students' ideas in order to find out more about how these could be seen in the light of the activation of these p-prims. Subsequently, a secondary task for teaching would be to promote these appropriate aspects of students' reasoning and knowledge that could be used for the construction of scientific understanding (Smith et al., 1996). The students' idea in this particular situation is faulty. Nevertheless, teachers could be relieved from the concern of eliminating this students' idea if instead of perceiving it as resulting from a totally faulty reasoning, they focus on this idea as potentially reflecting important aspects of scientific knowledge (Hammer, 1995). As students' responses showed, they were reasoning from everyday experiences, and they were trying to apply this experiential knowledge in the context of this particular situation. Therefore, in agreement with diSessa (1980), rather than trying to dismantle the idea that there should be an impetus for the cannonball to move towards the direction of the boat, a teacher could instead promote its adaptation toward a view that momentum is necessary to maintain motion. By conducting a discussion in which both the motion of the boat as well as the trajectory of the cannonball could be described in terms of stored momentum could possibly be an effective way that a teacher could choose to build on students' reasoning in order to make the distinction between the inappropriate activation of these p-prims in the particular context of this novel situation and the understanding of the explanation that the scientific account offers. Notwithstanding that although in this novel situation students' reasoning was in disagreement with the scientific account, there were other cases in which students' ideas were not inconsistent with the scientific account and thus, they could be considered more valid and productive in being chosen by the teacher for supporting them and building upon them towards scientific understanding. Examples of such valid ideas and reasoning can be seen above in the discussion of the novel situations (subsections 5.3.1-5.3.5).

What should be stressed here is that the intention of this subsection was not to offer a differentiation between the two perspectives on how each of them may influence a teacher in terms of direct instructional methods. Such an attempt would not be achievable as none of the two perspectives could warrant commitment in educational practices. According to Hammer (1996b) this is because neither perspective is sufficiently able to be trusted, nor is sufficient stable to enjoy general agreement in the community. In this sense, it would be unreasonable for teachers to accept that either the p-prims or the misconceptions perspectives or even both of them could be sufficiently used to determine appropriate intervention and teaching methods. On the other hand, the differentiation between the two perspectives could contribute to instructional decisions by affecting teachers' sense on how to facilitate students' progression from their experiential knowledge towards scientific understanding. In this regard, the examples and arguments discussed above provide suggestions concerning the way each perspective could affect a teachers' perception and intentions in terms of dealing with the most important factors which affects students′ learning in science; their existing knowledge prior to instruction.

Also, it is not argued here that either the misconception or the p-prims perspective is more valid in terms of being used by a teacher for conceptual change. Contrariwise, in agreement with Smith et al. (1993) and Hammer (1996b), the misconceptions perspective is one of the more valuable resources in terms of providing a teacher with a list of ideas and reasoning that can be used in order to help students understand scientific concepts, whereas the p-prims perspective offers an account on how to support students to construct scientific knowledge from their useful cognitive resources. To put it differently, either considering students' ideas as faulty conceptions or as having the potential to lead to scientific understanding, a teacher needs to focus on these ideas perceiving them as an interconnected system of intuitive and conscious ideas. As Brown (2010) argued, some of these ideas might be problematic, whereas others might be useful in providing starting points for conceptual change and scientific understanding.

5.4.3 Limitations of the study and suggestions for further research

The essential principles for conducting experiments in natural sciences are captured in Feynman's (1974) suggestion for utter honesty and leaning over backwards in all stages of conducting and reporting such research; and this precept could be extended and applied in other disciplines of science, like cognitive development and science education research (Bennet, 2013). According to Feynman:

> If you're doing an experiment, you should report everything that you think might make it invalid-not only what you think is right about it; other causes that could possibly explain your results; and things you thought of that you've eliminated by some other experiment, and how they worked-to make sure the other fellow can tell they have been eliminated. (p.11).

It is of great importance therefore to discuss the limitations of the methodology and the design of the present study and discuss not only how the research could be furthered using different methodologies but also how future research could contribute to the understanding of students' reasoning and ideas and how these are related with the use of analogies.

A severe limitation of this work is the fact that it was a localized study which was carried out in Greece and as such claims about the generalisability of these findings could not be made about students' ideas, reasoning and use of analogies in other countries. Although, it has been argued that children's ideas and views do not seem to be heavily culturally dependent (Driver et al., 1993), there are more recent studies which revealed some differences in the coherence of students' ideas across countries (e.g., Inagaki & Hatano, 2002; Clark et al., 2011). A continuing emphasis on this research with study samples from different countries will provide evidence on whether students of different cultural backgrounds use analogies in an attempt to reason about novel situations as well as the ideas they express in explaining these situations. Along this line, such a future research could reveal any differences in students' analogical reasoning and ideas, if any, as well as the nature of these differences. In agreement with Clark et al. (2011), the suggestion made here is that the identification of possible differences would provide an insight into designing curricula in such a way to offer better support to students around the world whose ideas and reasoning has not yet received enough attention. On the other hand, if there are not any differences identified, more attention should be paid to the commonalities of students' ideas and reasoning across different countries and how these could be confronted.

Also, the topics were limited in this research to areas selected by the researcher to serve the purposes of the study. Future research could focus on students' reasoning in other novel situations than these examined here in order to see whether reasoning spontaneously on the basis of analogies is a common way of understanding new situations. This could reveal if students' ideas identified in the literature could be understood as stemming from a similar way of reasoning using the same or similar analogies. For example, other topics that could be investigated are electricity, magnetism and forces which are areas well known for misconceptions.

Another limitation of this study concerns the data collection method. Although there is breadth of data in this study, there is less depth of data. As it was discussed in the methodology chapter (subsection 3.4.7) due to ethical issues and time restrictions, semi structured group interviews were conducted in order to provide additional data than these collected by the use of the questionnaires. Instead, individual interviews could have been conducted. A basic advantage of this type of design is the opportunity given to the researcher to gain a greater depth of students' understanding and way of thinking. Therefore, on-going research which would include the conduction of individual interviews could provide deeper insights about students' predictions and the way they reason in novel situations.

Additionally, the design of a longitudinal study would have been more appropriate in showing any differences across the different age groups. Although, it was decided to conduct a cross age study in order to identify the development of reasoning and use of analogies over the different age levels, having this way some of the features of a longitudinal study, the latter approach is considered to be more appropriate. This is because it could provide a deeper insight about the development of students' reasoning and use of analogies as they mature, offering this way a possible explanation about the persistence of students' incorrect ideas over several years. However, a longitudinal study was felt to be inappropriate for this research because it was designed to be completed within three years with the data collection lasting approximately three months. Future research could make use of such a design to investigate any differences and offer a deeper understanding of them.

Suggestions for future research also derive from a research perspective. Studies involving students' analogical reasoning are needed to further explicate the connection between students' ideas and the use of analogies. Also, in agreement with Ritchie, Aubusson and Harrison (2006) what has yet to happen is studying the relationship between classrooms discourses in which students' analogical reasoning is involved and where learning takes place. In this sense, more work needs to be done by the researchers who study learning and curriculum developers to identify these students' analogies that could be productively used and use them as the basis for instructional strategies relevant to these disciplines.

Moreover, in agreement with Taber (2008), neither approaches of students' ideas (other than the scientific ones) reflecting stable and consistent conceptual frameworks, as the misconceptions perspective implies, nor accounts of them being generated in situ, according to the p-prims stance, are in accordance with all the available research findings. As such, more work needs to be done to better understand the nature of students' knowledge as well as the degree of commonality of this knowledge among students of different ages. Understanding more about the nature and structure of students' knowledge as well as the differences of this knowledge as students mature could facilitate research and the development of curriculum design to support students as they restructure and build upon that knowledge. Taber (2008) and Hammer (1996b) argued that there is no direct need for a model in order for teachers to explain away whatever ideas students express, but rather suggestions on how to support their students and teach them how to use their ideas to develop appropriate ways of thinking that better match the scientific account. Therefore, further research is also indicated in order to relate students' knowledge to instructional strategies, curriculum models and relevant practical application of these strategies into classroom teaching.

Conclusions

This cross-age study investigated students' predictions in novel situations and the reasoning behind them. It was designed in such a way so as to present students with questions about novel situations that it was highly unlikely they would have encountered before. What was examined was whether students of different age self-generate analogies while they attempt to make predictions, the ideas they expressed in order to explain what led them to make their predictions as well as the compatibility of their predictions with the scientific perspective.

Answering the first two of the research questions governing this study (how do students of different ages make predictions about novel situations and whether they self-generate analogies) it was found that a common way for approaching and making predictions in the novel situations was that on the basis of analogies. The results showed that irrespective of students' age, at least four in every nine of them, in all six situations spontaneously self-generated analogies in order to explain what led them to make their predictions, whereas there were situations in which the percentages were much higher. Also, according to the findings, students who self-generated analogies did that to facilitate their understanding by seeing similarities between the novel, and hence unknown situation they were presented with, and other more familiar situations. These analogies students drew upon enabled them to perceive important aspects regarding the situation they were considering allowing this way to recall and use information necessary for them to proceed with their predictions.

In terms of compatibility of the predictions students made with the scientific perspective, the findings indicated that most of them (more than 80%) made a scientifically incorrect prediction regarding each novel situation they were presented with. The only exception to that was found in one of the novel situations in which students' high achievement was predictable and expected. This novel situation was actually used in this study to compare students' reasoning with another, similar situation from the remaining five. This comparison indicated that similar reasoning processes and the use of similar, and in many cases same, analogies can lead to different conclusions and predictions in terms of whether these are compatible with the scientific account.

The results, also, showed that the students of secondary education outperformed those of primary on making correct and scientifically accurate predictions and in the very few cases in which younger students were able to offer the correct answer they were unable to provide a scientifically accurate explanation (in most of these cases students' reasoning led to the assumption that they made the scientific prediction by chance). The comparison of the responses given by the students across the five age groups showed that the majority of them provided very similar, and in many cases identical, explanations. The only difference in students' responses across the five age groups was that the older students (aged 15 and 17 years) attempted to synthesize their ideas with something they learnt or heard in physics lessons merely by involving some scientific terminology in their explanations without however showing any correct understanding of the concepts they used. However, there were few older students who merely reasoned on the basis of scientific knowledge they learnt inside or outside school and came to a correct prediction. Although this could be interpreted as evidence that students make correct predictions only if they understand and can use scientific facts and reasoning, the findings of the study suggested that this is not always the case.

The latter is connected to the next and third research question, namely the answer in to what extent do students of different ages draw upon similar analogies, and whether similar analogical reasoning leads to the same predictions (compatible or incompatible with the scientific account). Despite that the analysis showed that in most of the cases it was the use of similar, and in many cases identical, analogies, gained from daily life experiences, by students across the five age groups which led to them making incorrect predictions, there were cases in which the use of such analogies had the potential to help students make a prediction compatible with the scientific point of view. Indeed, analogies which were based on students' experiential knowledge led some of them, more frequently the older (secondary education) ones, to make correct predictions. The fact that these analogies were similar to those which led other students to incorrect predictions suggests that it was the misapplication of these analogies (which had the potential to lead to correct predictions) and not the analogies themselves. This suggests that students, especially as they grow older, have made their observations well and they can use this experiential knowledge in such a way leading them to correct predictions and a subsequent better understanding of situations/phenomena. Moreover, there were few cases in which older students (secondary education), who made a correct prediction, not only used in their explanations concepts from curriculum lessons and textbooks showing a correct understanding of them but also, used these concepts as the basis of their analogy generation.

It emerged, therefore, that the better understanding of the analogous cases and the related scientific knowledge, which was the case of few upper secondary education students (whereas the others of the same age followed a similar reasoning and used similar analogies with those of younger students) resulted in the greater achievement of making the correct prediction on the basis of an analogy. These results provide evidence that analogical reasoning, which leads to correct predictions and understanding, develops according to the individuals' conceptual development rather than from a developmental change.

Moving on to the last research question of the study, it was attempted to assess whether the data collected offer any evidence of the existence of basic mental constructions (e.g., p-prims) arising from the explanations and the analogies that students used to make their predictions and whether the ideas students used could be seen as theory-like or as being fragmented. Although it cannot be argued that there was evidence found about the existence of p-prims in students' explanations, to a large extent the ideas students used were able to be interpreted in terms of p-prims documented in the literature. These ideas appeared not to be theoretically grounded but rather as having their origins in their everyday life experiences. The analogies students generated attest to that. In this sense, the findings of the present study suggest that students did not hold stable and coherent ideas as the misconception perspectives implies but rather, as their responses showed, that they had an unstable and fragmentary knowledge which was brought forward on the basis of the contextual features of the phenomenon/situation they were trying to understand and make a prediction for.

To conclude, the present study supports the idea that analogies can serve both as an instructional tactic as well as a research tool. The findings here suggest that self-generated analogies could be used as a potential approach for the identification of students' erroneous ideas which challenge the learning of science concepts as they can be used to reveal and assess students' prior knowledge. Also, analogies and the knowledge upon which these are based (even if this knowledge is scientifically incorrect) can be productively used in the teaching and learning of science. As Huxley (1894) wrote about science education, "all truth, in the long run, is only common sense clarified." (p.282). Therefore, it is important for students to be given the opportunity to connect reasoning in science with their common sense which, as the study showed, is actually their way of reasoning in their everyday life.

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Appendix A

Burning a candle: The scientific answer

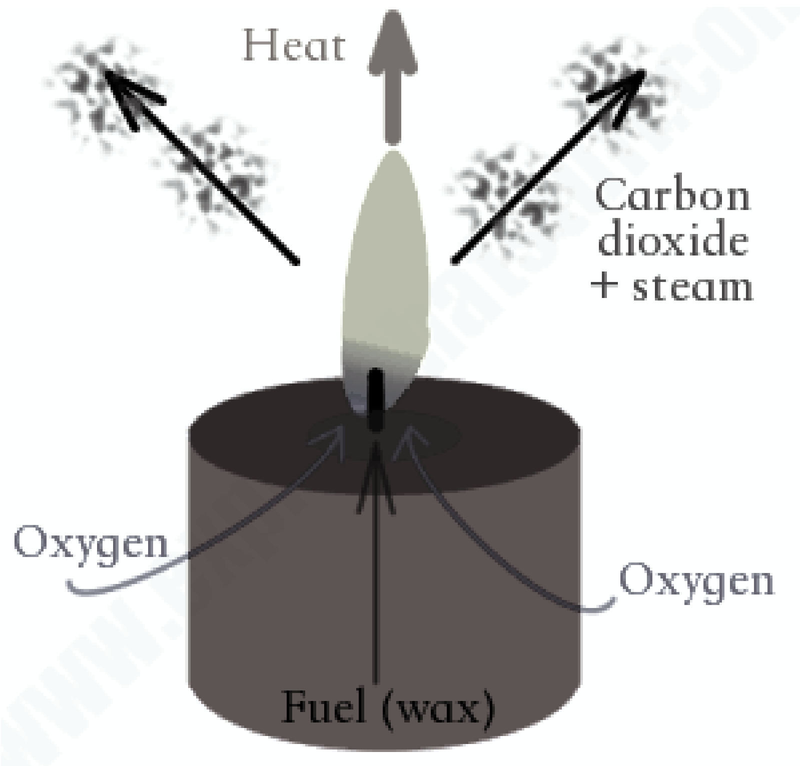


Image A.1 Burning a candle

When the candle is lit, wax in the wick and that on the top of the candle melt due to the heat. This liquid wax produced is drawn up the wick by a process known as capillary action which is actually the tendency of a liquid in an absorbent material to rise (or fall in other cases) as a result of surface tension. Because of this tendency, the liquid wax gets drawn up all the way into the flame. The liquid wax drawn to the tip of the wick becomes additional fuel for the flame to burn. Combustion of hydrocarbons (candles are made of paraffin, which is actually a mixture of hydrocarbons), which is an exothermic action occurring rapidly, takes place and the liquid wax gets heated up even more. Afterwards, the molten wax vaporizes converting from the liquid to the gaseous state which rises up as smoke from the flame causing this way the decrease in the mass of the candle. The balanced chemical reaction taking place can be summarized in the following equation.

Oxygen O_2 and paraffin C_nH_{2n+2} react. The burning produces water (H_2O) and carbon dioxide (CO_2). For n=1:

$$2\,O_2 + CH_4 = CO_2 + 2\,H_2O$$

Appendix B

Burning iron wool: The scientific answer

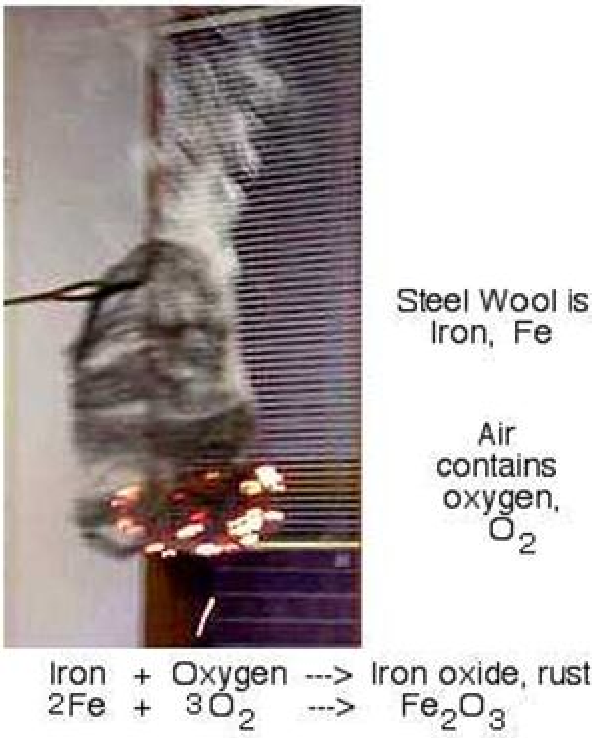


Image B.1 Burning of steel wool (Ophardt, 2003)

In this case there is a gain in the weight (or mass) of the steel wool being burned. If this situation is considered at the atomic level, the increase of the mass could be explained. The mass of the steel wool increases when the iron (Fe) is combined with oxygen (O_2) in the air. The balanced chemical equation for the burning, or combustion of iron wool is:

$$4\ Fe\ (s) + 3\ O_2\ (g) \dashrightarrow 2\ Fe_2O_3\ (s)$$

Appendix C

Objects falling in holes dug into the Earth: The scientific answer

The initial acceleration of the person who jumped into the tunnel would be the acceleration of gravity on the surface of the Earth:

$$g = \frac{GM_{Earth}}{R_{Earth}^2} = 9.8m / s^2$$

However, this acceleration becomes progressively smaller as the person approaches the centre of the Earth. As the image below shows, the weight of the person would be half in half of the distance from the surface to the centre of the Earth and zero as the person passes through the centre. This is because on the surface of the Earth, all of its matter lies below the person, but there is more and more of it surrounding the person as he falls into the tunnel. As the fall continues, there is an increasing proportion of mass above the head of the person exerting a growing counterforce to the proportionately decreasing mass below and therefore the acceleration slows as the person approaches the centre of the Earth in which the acceleration is zero.

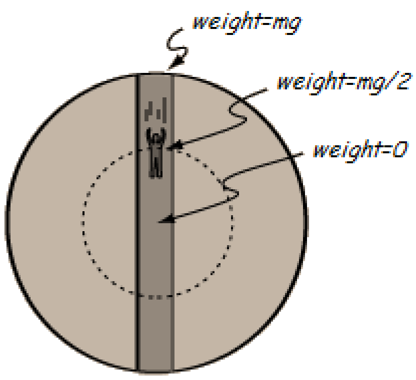


Image C.1 Differences in weight as the person flies into the tunnel

Assuming that the density of the Earth is uniform and by neglecting air friction as well as the existence of lava and the high temperature inside the tunnel that it would cause, the following would be true:

$$\boldsymbol{a} = \frac{GM(r)}{r^2} \qquad M(r) = \rho\frac{4}{3}\pi r^3$$

$$\rho = \frac{M_{Earth}}{\frac{4}{3}\pi R_{Earth}^3} \qquad \boldsymbol{a} = \frac{GM_{Earth}r^3}{r^2 R_{Earth}^3} = g\frac{r}{R_{Earth}}$$

According to Newton's second law and considering positive r as outward from the centre of the Earth, the following would be also true:

$$F = ma$$

$$F = -mg\frac{r}{R_{Earth}} = -kr$$

This force has the same form as Hooke's law for the force acting on a mass hanging on a spring. Therefore, the person would oscillate back and forth through the centre of the Earth like a mass oscillates up and down on a spring without stopping if air friction is neglected.

The period for this oscillation is:

$$T = 2\pi\sqrt{\frac{m}{k}}$$

$$T = 2\pi\sqrt{\frac{mR_{Earth}}{mg}} = 2\pi\sqrt{\frac{R_{Earth}}{g}}$$

However, in the case of taking into consideration the existence of air into the tunnel, this back and forth oscillation around either side of the mid-point of the Earth would eventually stop because air would slow down the motion of the person and thus would stop right in the centre of the Earth.

Appendix D

Weight and gravity: The scientific answer

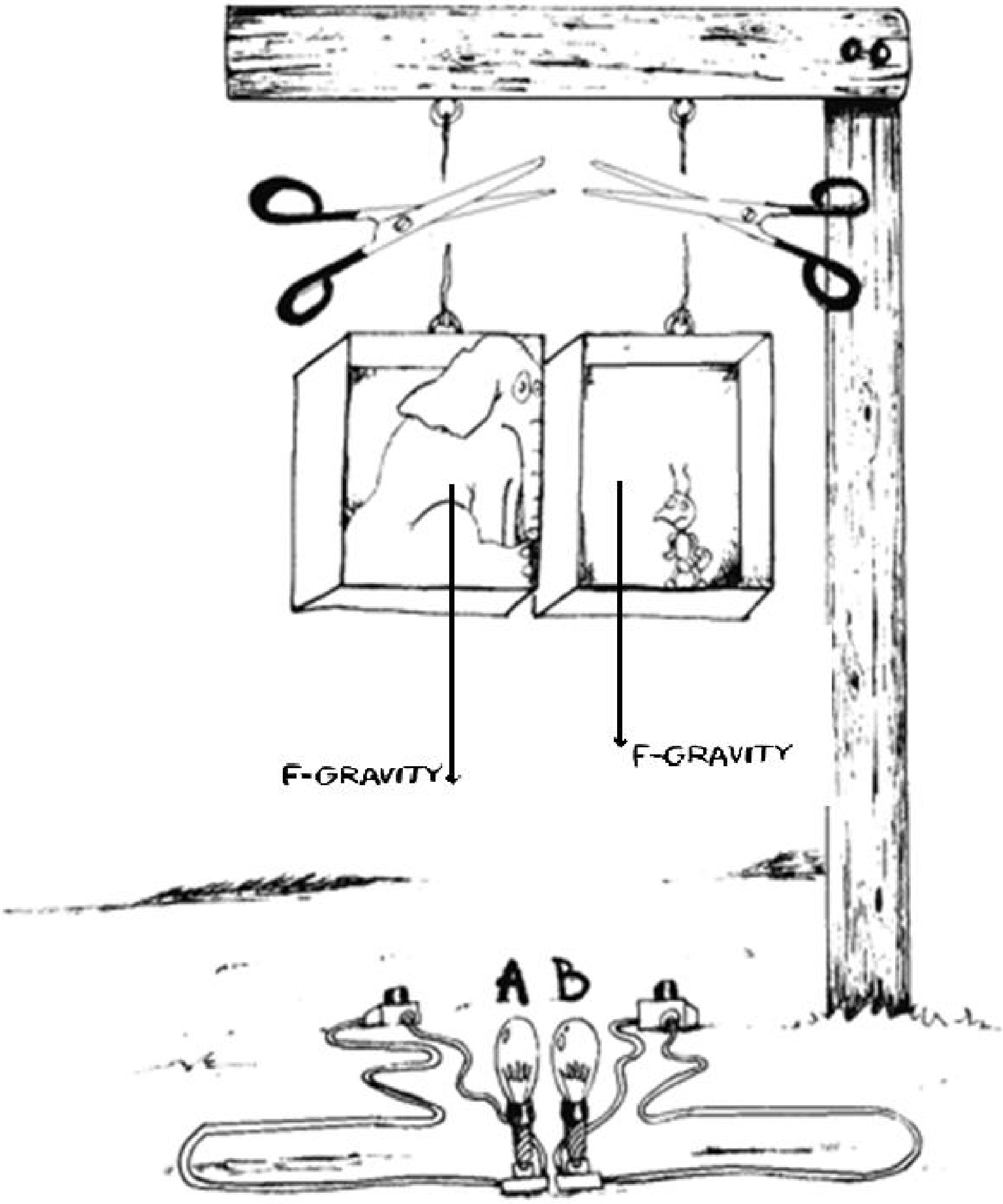


Image D.1 Weight and gravity

The scientific analysis of this situation demands an understanding of Newton's first and second law as well as the concept of terminal velocity. The image above provides a force diagram showing the forces acting upon the two objects in the case of no air resistance. The box with the elephant has a greater mass and thus, according to the first equation below, has a greater gravitational force. Being the product of the mass (m) and the gravitational field (g), this gravitational force can be calculated.

Also, as the second equations shows, acceleration also depends on the mass (in case of only one force on an object):

$$F = ma$$
$$a = \frac{F}{m}$$

Therefore, since both the acceleration and the gravitational force (the only force acting upon the two boxes) depend on mass, the following would be true:

$$a = \frac{F}{m} = \frac{mg}{m} = g$$

Although heavier things like the box with the elephant have a greater gravitational force, they do have a lower acceleration. With the only force acting upon the two boxes being that of gravity (without taking into consideration the air resistance), these two effects exactly cancel and thus make falling objects to have the same acceleration regardless of their mass.

Nevertheless, if air resistance (R), which is in the *opposite* direction to the gravitational force in both cases, is not omitted, the equation which describes the motion of both boxes is the next one provided:

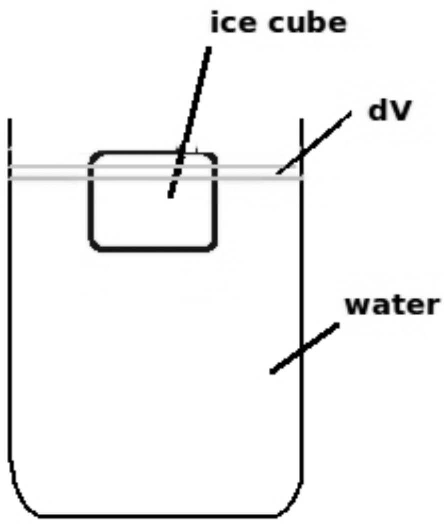
$$a = \frac{F_{\text{net}}}{m} = \frac{(mg - R)}{m}$$

Initially, both boxes accelerate (gain speed) because there is no force big enough to balance the gravitational force. Yet as they accelerate, they encounter an increasing amount of upward force; that of air resistance, which depends on the speed of the falling object and the frontal area of the falling object. With the boxes being of the same dimensions, it is only their speed which is responsible for the increase of the upward force. The boxes, continue to accelerate (gain speed) until the air resistance force increases enough to balance the gravitational force. Since the box with the elephant is heavier (more mass), it experiences a greater gravitational force and therefore, it would have to accelerate for a longer time in order to accumulate sufficient upward air resistance force to balance the gravitational force. The elephant will have to accelerate (gain speed) for a longer period of time. This way, this box will have a much greater terminal velocity than the one with the ant resulting in reaching the ground faster.

Appendix E

An ice cube in a glass of water: The scientific answer.

The situation can be easily explained basing on Archimedes' principle according to which any material thing, wholly or partially immersed in a fluid, is buoyed up by a force being equal to the weight of the fluid displaced by the material. In the case of a floating object, it displaces its own weight of fluid. Therefore, in this novel situation, the mass of the ice cube we put in the glass, equals mass of water displaced. Essentially, as the mass of ice reduces, less water is being displaced.



Basing on Archimedes' principle about a floating object:

$$B=A \Rightarrow m_{ice} \cdot g = \rho_{water} \cdot g \cdot dV$$

$$\Rightarrow m_{ice} = \rho_{water} \cdot dV \ (1)$$

Also,

$$\rho = m/V \ (2)$$

and

$$M_{water+ice} = m_{ice} + m_{water} \Leftrightarrow m_{ice} = M_{water+ice} - m_{water} \ (3)$$ (principle of mass conservation).

So, if we take into consideration the total volume of the system:

$$V_{total} = V_{water} + dV$$

$$^{(1)} \Rightarrow V_{total} = V_{water} + m_{ice} / \rho_{water}$$

$$^{(2)} \Rightarrow V_{total} = V_{water} + m_{ice} \cdot m_{water} / V_{water}$$

$$\Leftrightarrow V_{total} = V_{water} (1 + m_{ice} / m_{water})$$

$$^{(3)} \Rightarrow V_{total} = V_{water} (1 + M - m_{water} / m_{water})$$

$$\Leftrightarrow V_{total} = V_{water} / m_{water} \cdot M$$

$$\Rightarrow V_{total} = \rho_{water} \cdot M \text{ which is something constant}$$

In order for the aforementioned to be true, suffice is for the ice cube not to be in touch with the inner part of the glass, albeit even in this case the difference would be very slightly.

Appendix F

A firing cannon in a moving boat: The scientific answer

The scientific perception of this situation demands an understanding of frames of reference which are moving at a constant speed relative to each other. Someone being on the boat would be unaware of their movement. They would see the cannonball moving in a vertical direction relative to their frame of reference. On the other hand, observers on the ground would see the cannonball moving in a parabola relative to their frame of reference.

The cannonball is fired upwards already possessing an inertia towards the direction of the boat which continues moving at the same constant speed. The motion of the cannonball in this case is known as projectile motion and the path that the cannonball follows as projectile trajectory. At any point, this motion as well as the speed (the vector of speed) of the cannonball could be resolved in two perpendicular directions (Image F.1). The horizontal motion is unaffected by the vertical motion of the cannonball. It is only the vertical component which changes due to the Earth's gravitational force. The horizontal component stays constant for both objects (the boat and the cannonball). With distance being a function of time (d=vt), the velocity and the travelling time being equal for both objects, they cover the same distance d (Image F.1). This way, the cannonball falls back into the cannon from which it is released. Even in the case of air resistance (air friction), it can be proved that for low speeds the cannonball falls straight back into the cannon. The effect of air friction needs to be included only in cases of high speeds as it would reduce both components of velocity.

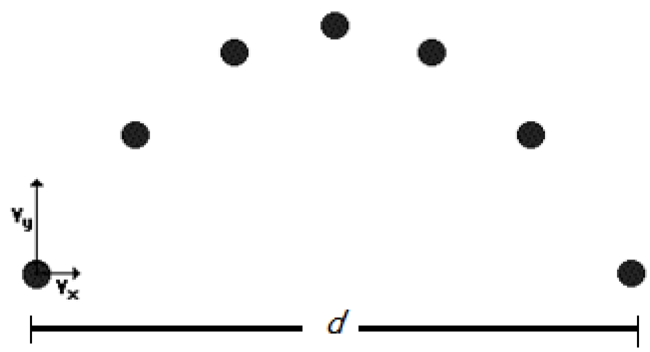
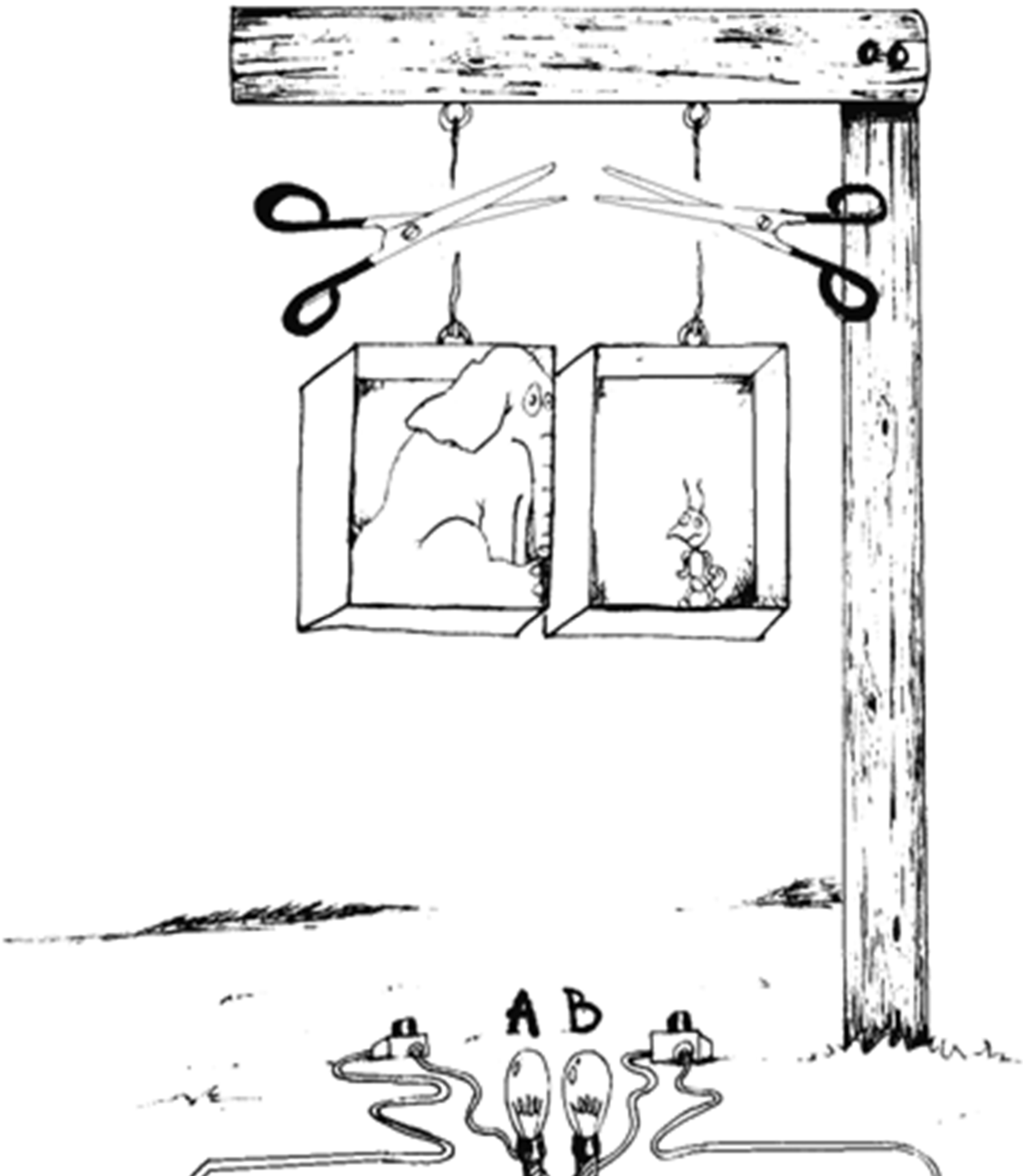


Image F.1 Trajectory of the cannonball as seen by an observer on the ground

Appendix G

The questionnaire

1.

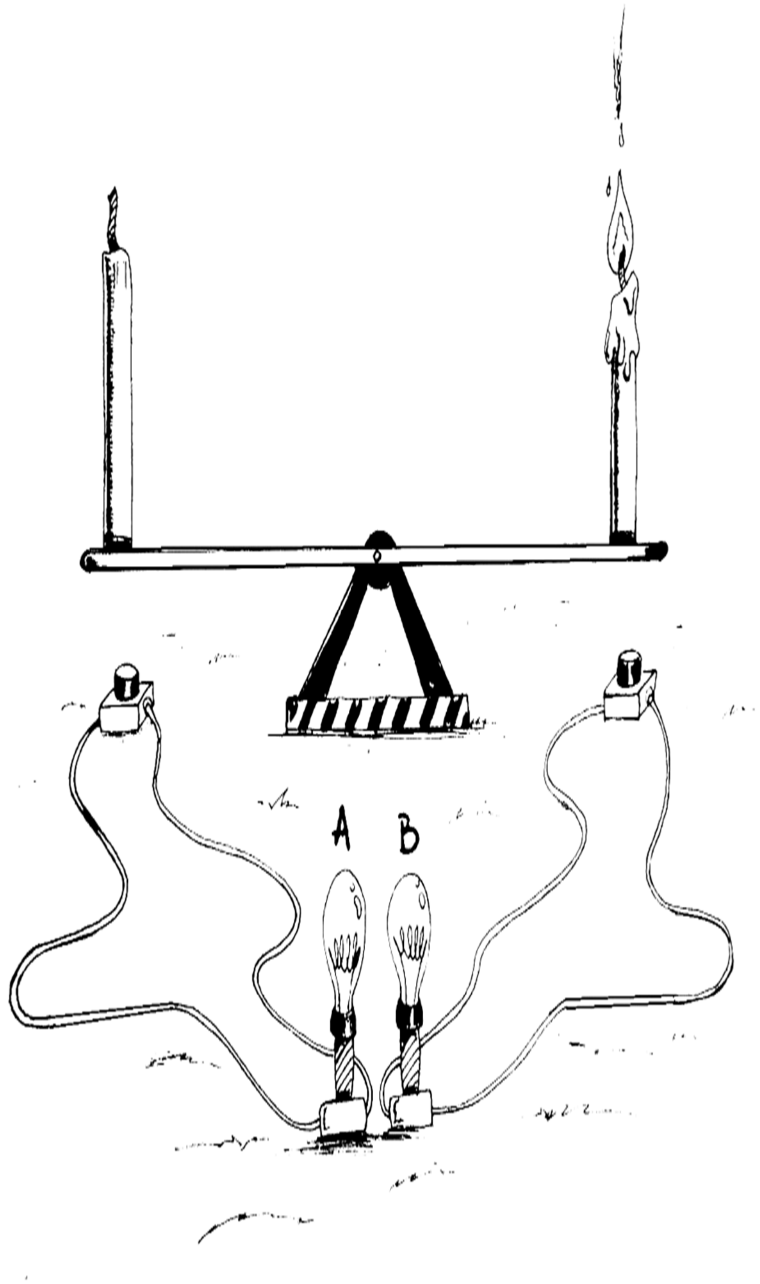


If the ropes shown in the figure are cut at the same time, will the bulbs be switched on at the same time or will one of them be first?

A) Both at the same time *B) Bulb A first* *C) Bulb B first*

In the space below please explain what made you think that way?

2.

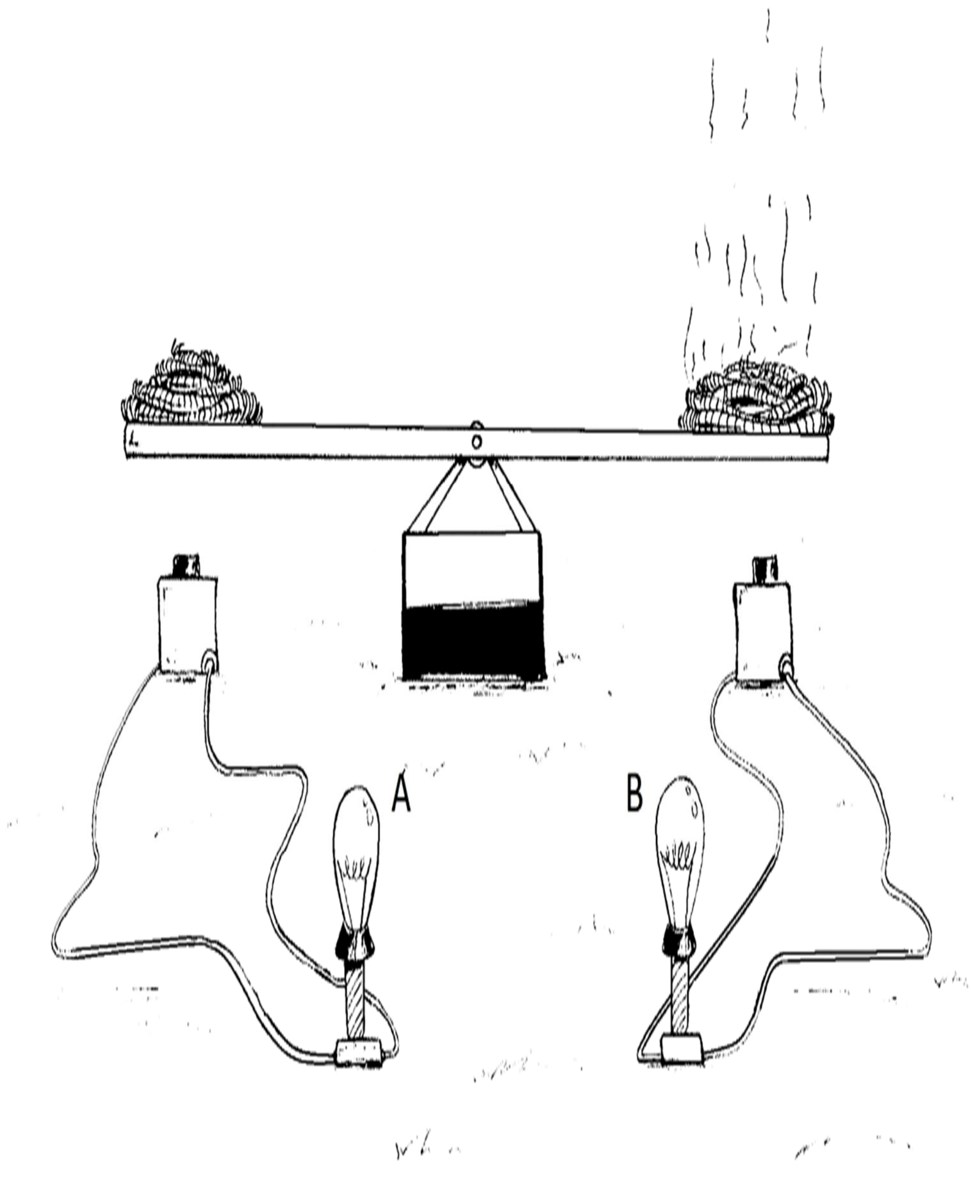


Two identical candles are balanced on a beam. After, we light one of the candles as shown in the figure. Will one of the bulbs be switched on? If yes, which one of the two?

A) Bulb A *B) Bulb B* *C) None of them*

In the space below please explain what made you think that way?

3.

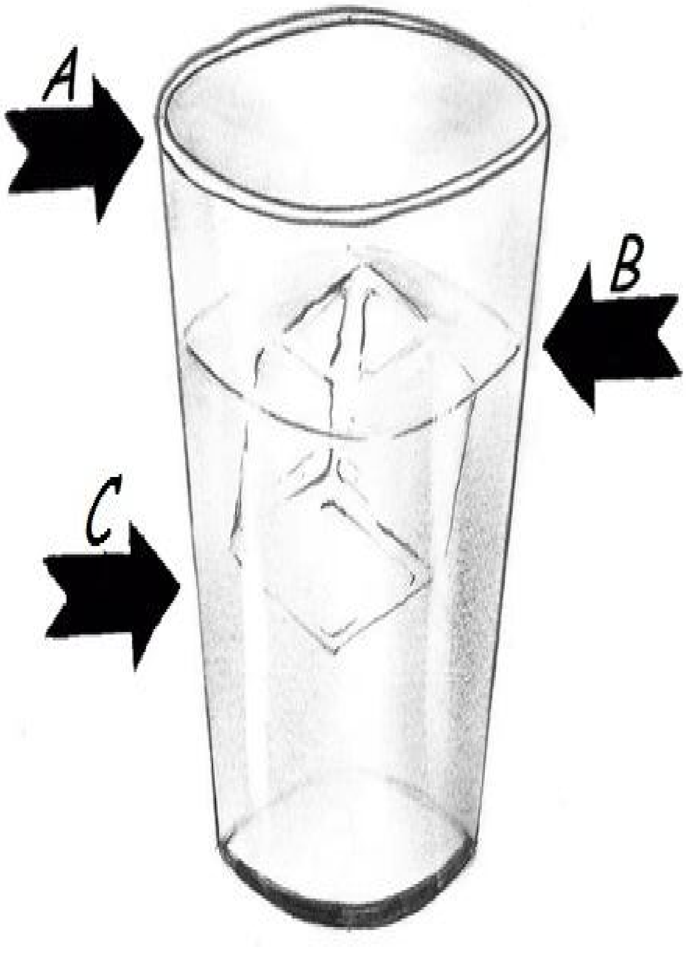


Two wire sponges which have the same weight are balanced on a beam. After, we light up one of them. Will one of the bulbs be switched on? If yes, which one of the two?

A) Bulb A *B) Bulb B* *C) None of them*

In the space below please explain what made you think that way?

4.

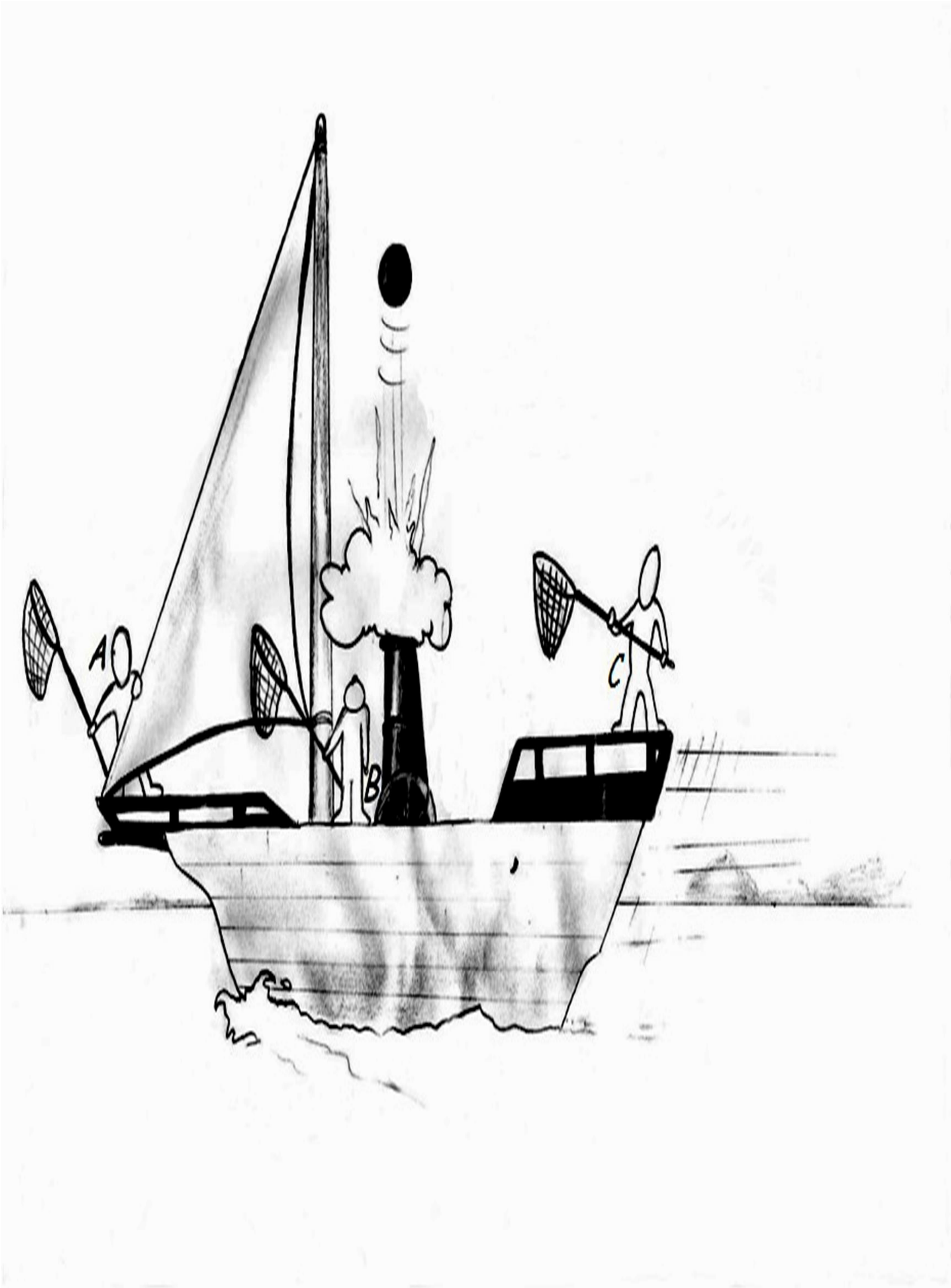


When the ice-cube melts, which of the three arrows will point at about the same level as the water level in the glass?

A) Arrow A *B) Arrow B* *C) Arrow C*

In the space below please explain what made you think that way?

5.

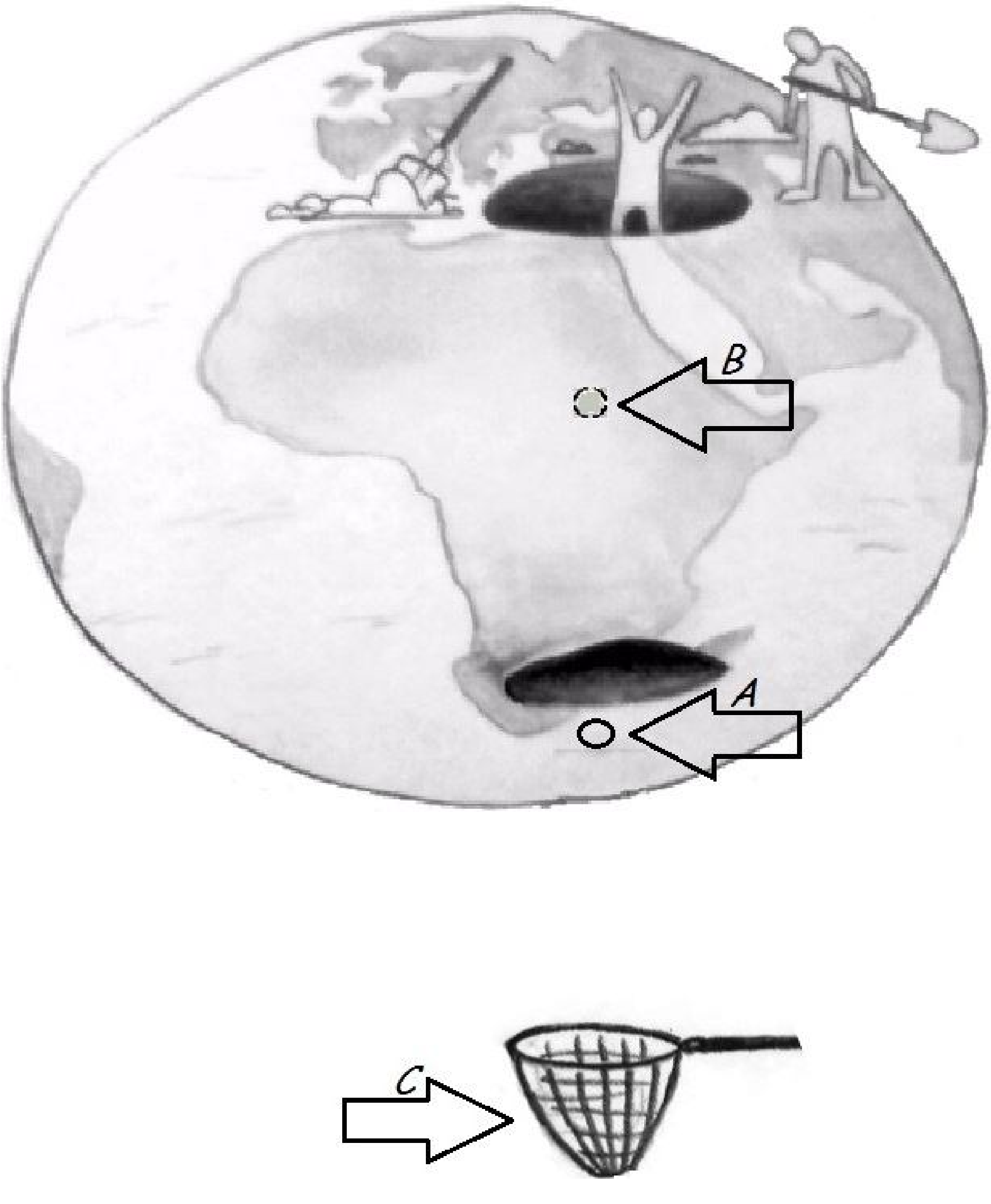


While the ship keeps on moving at the same speed, the cannon fires a ball (as the figure shows). Which person is more likely to catch the ball?

A) Person A *B) Person B* *C) Person C*

In the space below please explain what made you think that way?

6.



Two people have dug a huge tunnel straight down from the one side of the Earth to the other (as shown in the figure) and one of them jumps in. Where will this person stop?

A) On the other side of the tunnel *B) In the middle of the tunnel*

C) In the net

In the space below please explain what made you think that way?