THE COEXISTENCE OF ALTERNATIVE AND SCIENTIFIC CONCEPTIONS IN PHYSICS

DISSERTATION

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ABSTRACT

The purpose of this study was to inquire about the simultaneous coexistence of alternative and scientific conceptions in the domain of physics. This study was particularly motivated by several arguments put forward in opposition to the Conceptual Change Model. In the simplest form, these arguments state that people construct different domains of knowledge and different modes of perception in different situations. Therefore, holding different conceptualizations is unavoidable and expecting a replacement in an individual’s conceptual structure is not plausible in terms of instructional practices.

The following research questions were generated to inquire about this argument: (1) Do individuals keep their alternative conceptions after they have acquired scientific conceptions? (2) Assuming that individuals who acquired scientific conceptions also have alternative conceptions, how are these different conceptions nested in their conceptual structure? (3) What kind of knowledge, skills, and reasoning are necessary to transfer scientific principles instead of alternative ones in the construction of a valid model?

Based upon their academic backgrounds, two groups of participants were selected for this inquiry: one with minimal (non-physics group) and the other with high level of domain specific knowledge in physics (physics group). Data collection procedures were based on individually conducted problem-solving sessions. Throughout the problem
solving sessions, think-aloud method and retrospective questioning were used. Analysis of data was accomplished in three stages. In the first stage, a reference frame was generated for the nature of alternative conceptions by analyzing the data collected from the non-physics group. The second stage included the analysis of data collected from the physics group. The purpose of this stage was to present a context for the data collected from the physics group. In the third stage, the focus of analysis was to address the research questions. This stage consisted of the analysis of data collected from the physics group by referring to the reference frame outlined in the first stage.

Analysis of the data collected from the non-physics group indicated that the nature of alternative conceptions is framed by two types of reasoning: reasoning by mental simulation and semiformal reasoning. Reasoning by mental simulation was performed by mental images or scenes reproduced by the participants simultaneously by recalling their previous observations or experiences, which had not been refined or solidified into any kind of conceptual structure. However, semiformal reasoning was performed using previously constructed principles. The construction process of these principles refers to the perception of regularities in nature — repeatedly observed or experienced patterns are expected to happen in a similar way.

Analysis of the data collected from the physics group revealed that mental images or scenes feeding reasoning by mental simulation had not disappeared after the acquisition of scientific conceptions. It was explicitly noticed that the participants compartmentalized reasoning by mental simulation and scientific (formal) reasoning. They were always aware of which reasoning they were performing at a given moment.
They simply disregarded the products of reasoning by mental simulation and relied on scientific reasoning for their predictions.

The analysis of data also provided enough evidence to conclude that alternative principles feeding semiformal reasoning have not necessarily disappeared after the acquisition of scientific conceptions. However, in regard to semiformal reasoning, compartmentalization was not as clear as the case demonstrated in reasoning by mental simulation; instead semiformal and scientific reasoning are intertwined in a way that the components of semiformal reasoning can easily take their place among the components of scientific reasoning.

In spite of the fact that the coexistence of multiple conceptions might obstruct the transfer of scientific conceptions in problem-solving situations, several factors stimulating the use of scientific conceptions were noticed explicitly. These factors were categorized as follows: (a) the level of individuals’ domain specific knowledge in the corresponding field, (b) the level of individuals’ knowledge about the process of science (how science generates its knowledge claims), (c) the level of individuals’ awareness of different types of reasoning and conceptions, and (d) the context in which the problem is situated.
Dedicated to my sister Meryem
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CHAPTER 1

INTRODUCTION

It has been more than three decades since the constructivist view emerged in the cognitive and educational field of study as a theory of knowledge. Although there are several varieties in the movement of constructivism such as cognitive, information-processing, pragmatic, radical, and social, the main premise of this view contends that there is no way of knowing the reality independent of knowers. This general knowledge claim emphasizing the role of knowers forms the core principle of contemporary science instruction in a way that students do not passively accept scientific information; rather they actively construct their own meanings.

Two of these movements, radical and social constructivism, have gained special attention from the educational community. While radical constructivism defines knowledge as a result of individual experience, social constructivism defines knowledge as a result of social interaction and language usage, and interprets the knowledge as shared rather than as an individual experience. Although these two movements differ in the definition of knowledge, neither of them necessarily denies an absolute reality; instead, reality is defined within the realm of our experiential world (von Glasersfeld, 1995) or within the realm of social interaction—not in an ontological sense. The development of scientific knowledge throughout history provides the most striking instance of the change of assumed realities. For example, it was realized by scientists that

1
the principles defined by Newton do not work on very small objects or objects with very high speeds. With this realization, Newtonian principles were not reality anymore. Then, quantum mechanics appeared in the early 1920s to fill this gap. Now quantum mechanics seems to be solving many of the problems; however, no one can guarantee that it will work forever. Therefore, instead of reality, the term “validity” or “viability” is more appropriate according to a constructivist perspective.

Consistent with the view of radical constructivism, knowledge is defined as a product of an individual’s cognitive acts (Confrey, 1990). This definition rests on two epistemological principles: (a) Knowledge is not passively received from the environment, but it is actively constructed by cognizing subjects; and (b) knowledge acquisition is an adaptive process that organizes one’s experiential world, not the discovery of an independent world outside the mind of the knower (von Glasersfeld, 1995). However, it is not possible to ignore the social reality and its role in an individual’s knowledge construction. Therefore, it is necessary to extend these premises under the tradition of social constructivism. The personal theories, which result from the organization of the experiential world, must fit the constraints imposed by physical and social reality. This is achieved by a cycle of theory-prediction-test-failure-accommodation-new theory, and this gives rise to socially agreed theories of the world and social patterns and rules of language use (Ernest, 2003).

The main implication of the constructivist paradigm in science education can be summarized in one sentence—Individuals’ interpretations of their observations and experiences might be very different from that of scientists’. This avowal intrigued many researchers to explore how students develop their own conceptions corresponding to
scientific ideas. Although there are quite a number of studies in different domains, such as chemistry and biology, most of the studies have been conducted in physics. This is because many of the concepts in physics, especially in mechanics, have a wide range of applications in daily life situations and are a part of everyday language. Consequently, students are likely to make observations and have experiences that lead them to make inferences regarding the relationships among several concepts.

An immense body of research, conducted during the 1960s through the 1990s, revealed that students’ conceptions do not always match with scientifically accepted conceptions and they influence further learning (Driver, 1989). In this period of time, several labels were generated to refer to students’ pre-instructional conceptions, such as “pre-conceptions,” “misconceptions,” “alternative conceptions,” and “intuitive knowledge.” The key result of these studies, “prior conceptions influence further learning,” initiated a significant argument against a common-sense belief among numerous cognitive and educational researchers concerning students’ failure to understand physics concepts. According to these theorists, the Piagetian developmental stage of formal operational thinking is the prerequisite of learning physics concepts and students’ failure in learning these concepts is due to their under attainment of these stages (White, 1993a).

In the early 1980s, the psychological and philosophical base of this new paradigm had already begun to be established within the community of science education. It was recognized that alternative conceptions were a major problem in students’ understanding and this opened another window to explore students’ failure in acquiring scientific concepts. This realization stimulated many researchers to develop alternative learning
models to effectively deal with alternative conceptions. There appeared several models in the 1980s such as the Conceptual Change Model (Posner, Strike, Hewson, & Gertzog, 1982); Generative Learning Model (Osborne & Wittrock, 1983); and Learning Cycle (Champagne, 1988). Among these, the Conceptual Change Model received special interest from the educational community. Furthermore, in many cases, the Conceptual Change Model has been synonymous with constructivism in science education. The main reason for its power can be attributed to its strong epistemological base coming from the history and philosophy of science. The core inspiration behind the Conceptual Change Model are the ideas regarding the development of scientific concepts put forth by Kuhn (1970). Kuhn examined the development of scientific concepts throughout history, especially the phase when radical change occurs in the development of scientific conceptions, such as the transitions from Aristotelian view to Galilean, from Galilean to Newtonian, or from Newtonian to quantum physics.

Kuhn (1970) defines two different phases in the development of scientific concepts throughout history. The first one is “normal” science in which scientific ideas are developed upon previous ideas. In this phase, there is no challenging issue in terms of alternative conceptions—new ideas are just parallel with previous ideas and there is a smooth development. The second one is “revolutionary” science in which new ideas contradict previous ideas. In other words, new findings do not support the previous ideas. In this phase, it is necessary for scientists to make some regulations in their conceptual framework to accommodate the new idea. Kuhn’s work reveals that this regulation in the scientific community is not an easy process. The answer to the question of what makes this process so difficult is explained in terms of paradigm shift. Paradigm shift is defined
as a change from one way of thinking to another. Kuhn defines two senses of paradigm: the first one is global – shared commitments of a scientific community. These shared commitments refer to methodologies, concepts, definitions, theories, laws, rules, and models. The second one is more local and refers to just one of these laws, rules, models, etc. which comprises the global paradigm.

Based on these arguments related to the development of scientific conceptions in the revolutionary phase, Posner et al. (1982) developed the Conceptual Change Model (CCM). The arguments are very similar to the “paradigm shift” in a way that students also have previous ideas before they are introduced to scientific concepts and scientific concepts that might contradict their previous ideas. Instead of paradigm, Posner et al. used the term conceptual ecology to refer to the structure in which students’ previous ideas are nested. The term “conceptual ecology” had been introduced into the literature by Toulmin (1972) as an analogy between biological and conceptual environments. The idea behind this term is that the environmental characteristics of an ecological niche affect the natural selection occurring within its bounds; similarly, the logical characteristics of individuals affect the cognitive operations within their bounds. In the revised model of conceptual change, Strike and Posner (1992) outlined the basic characteristics of conceptual ecology. “Conceptual ecology consists of such cognitive artifacts as anomalies, analogies, metaphors, epistemological beliefs, metaphysical beliefs, knowledge from other areas of inquiry, and knowledge of competing conceptions” (p.150).

The basic argument behind the initial CCM is that learning is a rational activity and when students’ central concepts are inadequate to explain new phenomena
successfully, students must replace or reorganize their central concepts. Posner et al. (1982) identified several conditions to perceive a successful conceptual change. These conditions are: (a) There must be dissatisfaction with the existing conception, (b) a new conception must be intelligible, (c) a new conception must appear initially plausible, and (d) a new conception should suggest the possibility of a fruitful research program.

*Rationale for the Study*

After the initial CCM appeared in the literature, several critiques followed. These critiques can be summarized under two categories: cognitive and philosophical arguments. The cognitive arguments are about the over emphasis on rationality and neglect of non-cognitive factors, such as motivation and self-efficacy (Pintrich, Marx, & Boyle, 1993; West & Pines, 1983). In the revised model, Strike and Posner (1992) also shared these critiques. However, the philosophical arguments appearing in the early 1990s aimed at the core assumption of the CCM, the rationale for expecting a change in students’ conceptions.

These philosophical arguments oppose the requirement of expecting a “change” in students’ conceptual framework. In other words, the possibility, moreover the necessity of holding different conceptualizations is suggested. According to several philosophers (Berger & Luckmann, 1967; Schutz, 1967; Schutz & Luckmann, 1974), people construct different domains of knowledge and different modes of perception. Linder (1993) details these arguments with several examples concerning the coexistence of different conceptions in a scientific community, such as the coexistence of Newtonian mechanics and quantum mechanics. Newtonian mechanics, which held influence for several centuries, was found to be limited and gave way to quantum mechanics. According to the
CCM, Newtonian mechanics should be replaced with quantum mechanics; however, scientists did not replace it rather they kept both conceptions—Newtonian and quantum. Furthermore, they prefer to use the Newtonian conception to solve many of the mechanics problems.

In the same tradition, Mortimer (1995) also focuses on different ways of thinking in different domains. He contends that according to the nature of concepts, there might be several zones of conceptual profile. Mortimer clarifies his assertion with an example, the concept of matter. Possible zones of conceptual profiles are a realist view of matter (as something continuous), a primary atomistic view (matter as constituted of particles in motion in empty space), developed atomistic view (the atom as a system of sub-particles), and a quantum view (the atom as a system of quantum objects described by mathematical models). Although the last two zones of conceptual profile refer to scientists’ profiles, scientists also have other zones. In their everyday life, scientists also use matter as something continuous, but when they are confronted with problematic situations they shift to a scientific profile such as the developed atomistic view or quantum view. Then the question appears: What makes a conception legitimate or not? According to the constructivist view, the legitimacy of a conception refers to its validity. Several researchers (Engestrom, 1987; Linder, 1993; Ueno, 1993), especially in the tradition of situated cognition, contend that without defining a context it is not reasonable to judge a conception.

Within the frame of these arguments and research literature on students’ conceptions, expecting a replacement of alternative conceptions with scientifically accepted conceptions is not plausible. An individual’s ability to transfer scientific
conceptions to new settings and the durability of scientific conceptions can be a good indicator of whether the individual replaces the alternative conceptions or keeps them both. Several studies show that even after extensive conceptual change strategies, students’ alternative conceptions are not replaced (Galili & Bar, 1992; Tao & Gunstone, 1999). These studies show that students are apt to regress to their alternative conceptions in a short time or when they are confronted with new settings. Methodologically, regression to alternative conceptions does not necessarily mean that students did not acquire the scientific conceptions because in the initial phase and settings they can correctly use these conceptions.

All these philosophical arguments and research findings support the idea that individuals can keep multiple conceptions and they do not necessarily replace these conceptions when they are confronted with scientifically accepted conceptions. Therefore, more emphasis should be given to enhance students’ abilities to distinguish among different conceptualizations (Linder, 1993) and transfer them appropriately in different contexts rather than trying to create a conceptual change in terms of replacement.

Nevertheless, the implication of this instructional claim would remain ambiguous without a detailed answer to the question of what is the nature of alternative conceptions. Although it has been more than three decades since researchers began to realize the importance of alternative conceptions, the studies related to the nature of alternative conceptions appeared rather recently in the literature. Early interpretations were based on the parallelism between students’ alternative conceptions and early scientific conceptions, such as Aristotelian and Galilean views in mechanics. This parallelism stimulated several
researchers (e.g., McCloskey, 1983) to assume that alternative conceptions are theory-like conceptions. Although the CCM emphasized the integrated nature of conceptual ecology, in many research studies this aspect has been neglected and in many cases only superficial characteristics have been considered. Fortunately, in the mid 1990s, several researchers began to explore the nature of alternative conceptions in greater depth.

However, the studies related to the nature of alternative conceptions do not provide a coherent and consistent view. At this point in time, there are three dominant views concerning the nature of alternative conceptions: “knowledge as ontological categories” (Chi, Slotta, & Leeuw, 1994); “knowledge as fragmented pieces” (diSessa, 1988, 1993); and “knowledge as theoretical structures” (Vosniadou, 1994). Although these perspectives seem to be completely different from each other and the proponents of one perspective strongly criticize the others, it is not legitimate to accept one perspective and completely reject the others. These different perspectives create fuzziness and make it difficult to explore the possible roles of alternative conceptions.

Purpose of the Study

The main purpose of this study is to detail the arguments regarding the coexistence of alternative and scientific conceptions and to suggest implications for science education. Although there are convincing arguments about the necessity for the coexistence of different conceptions, there is no clue how these different conceptions are nested in an individual’s conceptual structure and how these different conceptions operate on different occasions. To reduce these two main questions into a researchable form, it is necessary to construct a framework for the notion of “conception.”
In the literature, studied under the heading of alternative conceptions or conceptual change, “conception” is implicitly defined as students’ constructed ideas about the corresponding scientific concepts. In some of these studies, a “conception” refers to a solution to a physics problem, such as “does a table exert a force on a book resting on it?” In other studies, a conception refers to an individual’s perception of an individual entity, such as force, heat, acceleration, mass, and weight. In still other studies, it refers to a constructed principle, such as “It is necessary to apply force to move an object.” Although these conceptions are different in terms of their functional characteristics, they are subsumed under the heading of conception. This assumption leads researchers to different interpretations regarding the nature of alternative conceptions. As a result, incoherent, fragmented, and sometimes contradictory perspectives appear to explain the nature and the role of alternative conceptions. Therefore, at the very beginning of this study it is necessary to provide a framework for the notion of “conception.”

**Conceptual Framework for the Notion of “Conception”**

In many cases, the definitions of variables provide a basis to create a theory, a principle, or a model. Vague or incomplete definitions cause theorists or researchers to end up with different interpretations. Unlike natural sciences, social sciences have many more variables to be considered, and usually they are completely intertwined. Consequently, this nature of social sciences such as education is not as rigorous as natural sciences. Nevertheless, the fruitful definition of terms has an essential role to minimize this disadvantage. In science, in general, the terms are usually defined in precise forms to introduce unusual or unfamiliar words, to coin new words, or to introduce a new meaning.
to a familiar word. However, the definition should not be too broad nor too narrow and be
in a manageable form. The development of theories (in terms of constructing the
relationships among different concepts) and the nature of encountered problems force
researchers to reexamine the definitions and redefine them. For example, in physics,
moving objects are studied under the term of motion. However, in our experiential world,
there are several forms of motion and each form should be interpreted differently rather
than combining all the forms under a single term of motion because defining motion in
general is not fruitful in terms of solving different kinds of problems. Categorizing
different kinds of motion such as linear motion, circular motion, and projectile motion
reduces this general term into more manageable forms. Similar examples can be given in
the cognitive or educational field of study. For example, when Flavell (1976) introduced
the term “metacognition” into the literature, he reduced this general term to a manageable
form by identifying different forms of metacognition such as metacognitive knowledge
and metacognitive experience.

The literature in the area of alternative conceptions and conceptual change has
been suffering from the lack of a manageable form for the notion of “conception”
because of the use of a single term, “conception,” for a multifaceted notion. To minimize
this conceptual confusion, at least three forms of “conceptions” should be identified
according to their functional characteristics. These forms are elements, principles, and
models.

*Elements.* Elements are definiendums of abstract entities such as force, mass,
velocity, acceleration, energy, heat, light, and sound. Many of these abstract entities are a
part of everyday language. However, the definiens of these abstract entities constructed in
a community may not be the same definiens constructed in a scientific community. The
difference can easily be attributed to the purpose of science. The purpose of science is not
only to explore these entities but also to capture the relationships among different entities.
The purpose of capturing the relationships among different entities forces scientists to
find fruitful definiens for entities. In other words, the relationships among different
entities constrain the definiens of each entity. For example, the entities of “time” and
“distance” constrain the entity of “velocity” \( v = d/t \). Similarly, the entity of
“acceleration” constrains the entity of “force” \( F = ma \). Although it is not legitimate to
judge any sort of definition attributed to an entity, it can be judged in terms of its
fruitfulness for a community. It is so natural to find different definiens of the same entity
throughout different communities. For example, the entity of “sound” might be defined
differently in a community of physicists and in a community of musicians.

Based on the constructivist tradition, definiens of entities are assumed to be the
reflections of ontological reality. Therefore, they have either explicit or implicit
ontological characteristics attributed by individuals. Chi and her colleagues (1993,1994)
cover this aspect of conceptions. Their studies clearly show that students’ definiens and
scientists’ definiens differ in terms of attributed ontological characteristics. More details
and examples about the ontological categories are provided in the literature review
section.

**Principles.** Principles refer to abstractions of natural or artificial events. These
abstractions are accomplished by capturing the relationships among different elements
through inductive reasoning. The difference between construction of scientific principles
and construction of alternative principles can simply be attributed to the difference between “experiment” and “experience.”

Prediction is one of the endeavors of scientific studies; therefore, science searches for general principles. Seeking general principles is accomplished by scientific methodologies such as controlled observations and experiments. However, an individual’s endeavor is to cope with everyday-related situations and not to find general principles. Therefore, the principles constructed by individuals are mostly in simplest form and context dependent. Developing these context-dependent principles begins in infancy and occurs naturally throughout one’s life by capturing the patterns from experiences and observations in daily life situations. “Heat is transferred from a warmer object to a colder,” “It is necessary to give some force to move an object,” “Objects drop when they are released,” “Mirrors reflect the inverse of an object,” “Without giving a steady force, objects will stop at some point in time,” and “Elastic objects bounce when they hit a hard surface” are some examples of principles that individuals may easily develop from daily life experiences. They differ from scientific principles in several ways:

1. They are just the patterns individuals capture from daily life observations and experiences. In other words, the necessary processes, such as constructing hypotheses and testing them in different contexts are skipped in their construction.
2. The elements constructing the principles are not elaborated. In science, elements are defined operationally—their definitions are constrained with other elements.
3. Definitions are dynamic in the period of development of scientific principles. By going forward and backward throughout the development of principles, the
definiens of elements are optimized to get the best working relations among different elements. However, an individual’s development of principles is based on stable definiens of elements, which are mostly socially constructed. Therefore, it is almost impossible to discover general (context-independent) principles based on the definiens of everyday language, which are not operationalized.

It would not be an overgeneralization to claim that there are implicit or explicit epistemological beliefs behind the construction of any principles. For scientific principles, this epistemology refers to the validity and reliability of the methodology and instruments used throughout the development of principles. This is a shared and well-defined epistemology and constructs the justificatory system for the validity of any sort of knowledge claim in a scientific community. However, from an individual’s perspective, there is no well-defined explicit epistemology in the process of constructing alternative principles.

Since individuals have no need to find general principles, and there is no well-defined procedure to reach these principles, and they are context dependent, it is logical to claim that they are “fragmented pieces” (diSessa, 1993). Many of the assertions made by diSessa in his interpretation about the nature of alternative conceptions are valid for these alternative principles. Alternative principles can be considered as an intuitive equivalent of physical laws; they are not themselves explained (just regarded as an expected event), but they explain other phenomena.

Models. Models refer to explanations that an individual offers for encountered problems. Models are the result of a cognitive process, more specifically the result of deductive reasoning that is constructing a representation by transferring “appropriate”
principles into the problem situation. Quite a number of studies in the conceptual change literature focus on students’ responses to several physics problems. In many of these studies, it is assumed that students have already stored knowledge about these problems and their responses reveal their alternative conceptions. However, it is not a retrieval of already stored knowledge, instead it is an active process, and the model is a result of this process. Even if there is an already stored answer for an encountered problem, from an educational point of view, the importance is not the answer but the process behind the answer. Therefore, models should not be considered as an individual’s stored conceptions, but rather as a result of a process created in response to encountered problems.

It would be naïve to assume that if students have already acquired scientific elements and principles then they would certainly transfer them when they are confronted with problems. From a methodological standpoint, it is also naïve to claim that students did not acquire scientific elements or principles by looking at students’ answers to several problems. The nature of the coexistence of alternative and scientific conceptions creates the possibility of transferring alternative principles and elements in problem-solving situations, especially everyday-related problems, because alternative elements and principles are developed in everyday context.

Significance of the Study

The review of the literature in the area of alternative conceptions and conceptual change reveals that the notion of conception is not defined in an appropriate form to cover the different facets of the notion of conception. From a methodological standpoint, this situation creates ambiguity and leads researchers to take different theoretical
positions regarding the nature and the role of alternative conceptions. This study proposes a framework for the notion of conception to unveil the ambiguity and to suggest a unified model for the nature of alternative conceptions by explicitly defining the different facets of the notion of conception. Defining different facets of conceptions not only gives us a more detailed picture to understand the nature of alternative conceptions, but also provides a framework to examine the plausibility of the developed learning models based on students’ alternative conceptions.

Several arguments about the coexistence of alternative and scientific conceptions put forth by researchers in the tradition of social constructivism and situated cognition have stimulated this study to explore the conceptual structure and cognitive processes of individuals who have already acquired scientific elements and principles. This study intends to (a) find evidences about the coexistence of different conceptions (elements and principles), (b) understand the structure of coexistence in an individual’s conceptual framework, and (c) understand the process of constructing a model in response to encountered problems.

Taking a position in favor of the simultaneous coexistence of alternative and scientific conceptions instead of conceptual change requires this study to consider the possibility of transfer of alternative conceptions inappropriately in problem-solving situations. Several studies show that while students correctly transfer the necessary scientific principles in one context, they transfer the alternative principles when they are confronted with a different context. Therefore, identifying the necessary knowledge, skills, and reasoning to construct appropriate models in problem-solving situations provides essential insights for practice in science classrooms.
Research Questions

This study is based on philosophical arguments against the CCM in terms of replacement of alternative conceptions. Based on the claim of the simultaneous coexistence of alternative and scientific conceptions, the purpose of this study is to find evidences for the coexistence and to investigate the structure of this coexistence. The nature of this study limits the sample to individuals who have already acquired scientific conceptions. However, because the notion of “conception” is too broad for this investigation, three forms of conceptions—elements, principles, and models are proposed. Based on this framework, three initial questions appear:

1. Do individuals keep their alternative conceptions after they have acquired scientific conceptions?
2. Assuming that individuals who acquired scientific conceptions also have alternative conceptions, how are these different conceptions nested in their conceptual structure?
3. What kind of knowledge, skills, and reasoning are necessary to transfer scientific principles instead of alternative ones in the construction of a valid model?

Overview of the Methodology

This study is mainly interested in individuals’ conceptual knowledge and its function in the domain of physics. Three facets of conceptual knowledge: elements, principles, and models are the core objects of this investigation. Two dimensions of these facets were explored in terms of alternative and scientific conceptions.
According to their academic background, two groups of participants were selected and labeled as Physics-group (P-group) and Non-physics group (NP-group). The research questions of this study inherently required participants (P–group) who had already acquired scientific conceptions to investigate the coexistence of alternative and scientific conceptions. However, it was also necessary to establish a reference frame for alternative conceptions. For this purpose another group of participants (NP-group) whose scientific knowledge is minimal in the defined domain was identified as a reference frame.

The data collection procedure was based on individually conducted problem-solving sessions. Six physics problems were identified for the problem-solving sessions. Several criteria were established for the selection of these problems such as the problems should be embedded into everyday-related situations, should be interesting and challenging to the participants so they would be motivated to come up with a solution, and should not require complex algebraic manipulations. Throughout the problem-solving sessions, think-aloud method and retrospective questioning were used to collect data.

**Limitations**

The qualitative nature of this study brings some restrictions on the sampling procedures. According to the purpose of this study, a small number of individuals were selected as the participants of this study. This selection was based upon several established criteria; consequently, it reduces the external validity of this study. The results from this study may only be generalized to individuals whose credentials are similar to the ones studied.
In terms of internal validity, the most important argument worth mentioning here is the possibility of the effect of verbal reporting on cognitive processes. On this issue, the argument of Ericsson and Simon (1993) was taken as an assumption for the data collection procedure of this study. According to these theorists:

Information may reach, and be stored in, memory in a variety of encodings—visual, auditory, tactile. In first approximation, at least, the aural (afferent) encoding and the articulatory (efferent) encoding of oral language can both be represented as strings of phonemes. Without trying to decide whether the encodings are identical or simply nearly isomorphic, let us designate both as the oral encoding. Now our fundamental assumption is that when the cognitive processes attends to or activates a structure in the memory that is orally encoded, then this structure can at the same time be vocalized overtly without making additional demands on processing time or capacity. (p. 63)

This chapter provided an overall introduction by presenting the rationale and the purpose of the study and establishing the research questions. Discussions about the significance and limitations of the study were also included in this chapter. In the following chapter, a review of the literature is provided.
CHAPTER 2
REVIEW OF LITERATURE

During the last three decades, research in science education, especially that focused on students’ ideas about scientific concepts, has inspired the educational community to consider a constructivist view of learning in science education. This view suggests that students’ ways of perceiving their environments might be very different from those intended by educators (von Glasersfeld, 1996). The assumption that individuals spontaneously acquire knowledge about natural phenomena through their experiences or observations has stimulated the studies on students’ pre-instructional conceptions, which are labeled as “alternative conceptions,” “misconceptions,” “preconceptions,” or “intuitive knowledge.” The immense body of research based on students’ qualitative understandings of basic concepts has shown that these alternative conceptions do not always fit scientifically accepted conceptions and they influence further learning (Driver, 1989). One of the latest bibliographies of research papers (Pfundt & Duit, 1994) contains thousands of studies related to students’ alternative conceptions. Empirical findings from these studies reveal that the influence of students’ prior knowledge, memories, and experiences on learning science has been underestimated (Osborne & Wittrock, 1983).

The realization that in spite of instruction students continue to hold their own explanations, led researchers to generate alternative models of learning and instruction.
Posner et al. (1982) developed a model of science learning, The Conceptual Change Model (CCM). Following the CCM, several alternative instructional approaches were developed in the 1980s, such as the generative learning model (Osborne & Wittrock, 1983) and learning cycle (Champagne, 1988). Among others, the CCM gained a lot of attention from both researchers and educators due to its coherent rationale and rigorous theoretical base (Hendry, 1992). Although it became the leading paradigm guiding the research and instructional practices in the area of science education for many years, it also became subject to a number of criticisms (Vosniadou, 1999). These critiques can be summarized under two categories: cognitive and philosophical arguments. The cognitive arguments are about the over-emphasis on rationality and ignorance of non-cognitive factors, such as motivation and self-efficacy (Pintrich et al., 1993; West & Pines, 1983). Beyond the role of non-rational factors on learning, Pintrich et al. also questioned the key metaphor of the CCM, “students as scientists.” The differences between the scientific community and learning communities in science classrooms are discussed in terms of their aims and institutional conditions.

However, the philosophical arguments appearing in the early 1990s aimed at the core assumption of the CCM, the rationale for expecting a change in students’ conceptions. This study is particularly related to these arguments against expecting a change in terms of replacement of alternative conceptions with scientific conceptions. Nevertheless, it is important to provide a general picture of the conceptual change studies to construct a coherent view of this literature. For this purpose, the literature will be reviewed in four sections.
In the first section, the rationale, premise, and the conditions of the CCM will be summarized. The next section will include general instructional strategies used in the conceptual change literature. In the third section, three important theoretical perspectives regarding the nature of alternative conceptions and the expected change will be provided. Finally, the arguments against expecting a replacement in students’ conceptual frameworks will be reviewed in the fourth section.

**Conceptual Change Model**

Posner et al. (1982) proposed the CCM as an epistemological theory based on Kuhn’s (1970) study of the history and philosophy of science, *The Structure of Scientific Revolutions*. The basic assumption of the CCM is that there is a similarity between students’ learning of new concepts and the “paradigm shift” (Kuhn) experienced in the scientific community throughout the development of scientific conceptions. Transition from the Aristotelian view of mechanics to the Newtonian view is a good example to illustrate this shift in the history of science. This key metaphor of the CCM, students as scientists, is derived from several articulated studies showing that students’ alternative conceptions about mechanics are “similar” to the Aristotelian or Galilean view of mechanics (McCloskey, 1983) and they are resistant to modification by instruction.

Under the shed of this metaphor, the CCM seeks to understand and explain how individuals make replacements or transitions in their conceptual framework when they are confronted with new (scientific) explanations. Posner et al. (1982) define two kinds of conceptual change according to the compatibility of students’ alternative conceptions with scientifically accepted ones. If alternative conceptions are compatible enough to deal with new phenomena, this expected change is called “assimilation,” and if alternative
conceptions are inadequate or incompatible to explain new phenomena, more radical change is necessary which is called “accommodation.”

The underlying premise of the CCM is that learning is a rational activity. Strike and Posner (1992) define the concept of rationality according to historicists and philosophers of science and transfer this notion to science learning. Referring to history and practice of science as a source of rationality, Strike and Posner state that rationality cannot be characterized solely as formal logical operations attached to the uninterpreted experiences; instead, the broader sense of mechanism attributed to the scientific method or procedures should be considered. The background of current conceptions constructs the major component of rationality for scientific reasoning.

This perspective argues that scientific method cannot be characterized solely by formal logic. Instead, the approach to scientific problems is generated by substantive belief systems such as Kuhn’s (1970) paradigms or Lakatos’s (1970) research programs. “These substantive conceptions suggest what are to count as problems and what is to count as relevant evidence. Indeed, they provide the perceptual categories by which the world is perceived” (Strike & Posner, 1992, p.151). This interpretation does not identify the current conceptions merely as individual objects of cognitive processes; instead it reveals their integrated nature. Moreover, current conceptions are considered as processors of cognition.

Similar to the concept of paradigm or research program developed in the history and philosophy of science, Posner et al. (1982) propose “conceptual ecology” (following Toulmin, 1972) in which learning takes place. Several components of conceptual ecology are identified as anomalies, analogies, metaphors, epistemological beliefs, metaphysical
beliefs, knowledge from other areas of inquiry, and knowledge of competing conceptions. Bordering on the paradigm defined in the history of science, conceptual ecology has a substantial role in rationality. The only tool to make judgments about new concepts is the individual’s conceptual ecology. This intriguing structure of conceptual ecology has stimulated the studies on the nature of students’ alternative conceptions. Before proceeding to review several different views related to the nature of alternative conceptions, it is important to provide another important element of the CCM, conditions for a successful conceptual change. By defining learning as a rational activity, Posner et al. (1982) suggest four conditions to be fulfilled before the accommodation of a new conception.

1. There must be dissatisfaction with the existing conception. According to Posner et al. (1982), individuals do not accept the new conception easily until they realize that their alternative conception does not work anymore. The most common instructional approach to create dissatisfaction with prior conceptions is using anomalous data (anomalous data will be detailed in the instructional strategies section). Without considering conceptual ecology, one can expect students to give up their alternative conceptions easily when they are confronted with anomalous data, but this is not the case. The integrated nature of conceptual ecology does not let the formal logical operations change the alternative conceptions. Therefore, the characteristics of the new conception have crucial importance in the conceptual change process.

Hewson and Thorley (1989) termed the following three conditions (i.e., intelligibility, plausibility, and fruitfulness) concerning the new conception as a status of an individual’s conception. With this terminology, Hewson and Thorley defined the
conceptual change process as lowering the status of alternative conceptions and raising the status of scientific conceptions.

2. A new conception must be intelligible. Hewson and Thorley (1989) suggest several questions identifying whether the conception is intelligible or not to the learner: “Does the learner know what it means? Do the pieces of the conception fit together for the learner? Is the learner able to find a way of representing the conception? Can the learner begin to explore the possibilities inherent in it?” (p. 542). Although it is not explicitly stated, many of the studies in the conceptual change literature are aimed to increase the intelligibility of the new conception. Instructional strategies such as using analogies and anchoring conceptions are used widely to increase the intelligibility of the new conceptions.

3. A new conception must appear initially plausible. Plausibility refers to the individual’s belief about the truth of the new conception. It is not possible for an individual to find a conception plausible without finding it intelligible. The relationship between the new conception and some features of an individual’s conceptual ecology has a significant role in the plausibility of the new conception such as the consistency with past experiences, compatibility with existing conceptions, and consistency with personal standards of knowledge (Hewson, 1981). “The personal standards of knowledge” element of conceptual ecology seems to be the most important element for the plausibility of new conceptions. One of the basic issues in science education is to help students understand what makes the scientific conceptions powerful. In other words, students need to comprehend what reliability, validity, and generalizability mean, and what the procedural differences are in reaching a scientific theory and alternative conceptions.
4. A new concept should suggest the possibility of a fruitful research program. The fruitfulness of a new conception refers to its potential to be a productive cognitive tool in problematic situations. There is no doubt that transferring the new conception to other settings must be an essential purpose of the CCM. However, less attention has been given to the fruitfulness of the new conception in the conceptual change literature.

*Conceptual Change Strategies*

In fact, it has to be stated that there is no single study listed in the leading bibliographies of research on students’ conceptions (Carmichael et al., 1990; Pfundt & Duit, 1994) in which a particular student’s conception of the above deep-rooted kind could be completely extinguished and then replaced by a new idea. Most studies show that the old ideas stay “alive” in particular context and that there is only quite limited success concerning the acceptance of the new ideas. (Duit, 1999, p. 270)

It is difficult to find ready-to-use instructional strategies in the literature aimed to achieve a successful conceptual change because it depends on both students’ alternative conceptions and the nature of scientific conceptions in the defined domain. However, there are several commonly used strategies derived from the conditions of conceptual change presented in the previous section.

One of the most important elements of teaching for conceptual change is identified as communication between students and teachers, and understanding what each other means with their terminology. Stenhouse (1986) discusses this issue in his article about “language-games.”
Stenhouse (1986) suggests that understanding a concept is to be equated with knowing the rules for the use of a word or symbol. Speaking with Kuhn’s terminology, there are two paradigms in a classroom context, student’s science and teacher’s science. These two paradigms have different “language-games” and the communicatory relationship might be asymmetric. Although the terms used in physics class such as “force,” “acceleration,” and “energy” are the same terms used in the social context, the meanings attributed to these terms are different in everyday context and scientific context. Therefore, students are unlikely to see themselves unable to understand, instead they are likely to consider what the “teacher’s science” is saying as meaningless or self-contradictory related to their perspective.

For example, “teacher’s science” says that a table exerts an upward force on a book resting on the table; however, the meaning of force for “student’s science” is different from the meaning of “teacher’s science.” From the students’ interpretations of force (force can only be applied by humans, animals, or some machines; nonliving things cannot apply a force), this statement of “teacher’s science” will be meaningless. Thus, it is an important element of conceptual change teaching to identify and understand students’ language-games before any attempt to introduce a new concept because it is a contradiction to students’ alternative conceptions. This situation can be identified and dealt with through meaningful discussions. When we return to our example of upward force exerted by the table, which is an application of Newton’s third law, the very problematic issue is students’ understandings of the force concept before conceptualizing Newton’s third law. As discussed by Brown (1989), without conceptualizing the
scientific meaning of the force concept, it is not possible for students to conceptualize
Newton’s third law.

Using Analogies and Anchoring Conceptions

Several studies claim that analogies and exploratory models (Brown, 1993, 1994; Clement, Brown, & Zietsman, 1989) facilitate the conceptual change process. For example, Brown (1994) conducted a study with 73 high school students. Each student received an explanation, which consisted of seven short paragraphs addressing the question of whether a table exerts an upward force on a book resting on the table. Before and after reading the explanations, students were asked to give an answer and explanations to the question of whether a table exerts an upward force on a book resting on the table.

The purpose of the explanations was to construct bridging analogies. Three sequences of analogies were provided. The first analogy was students’ “anchoring conception” which is the conception that most students believe that there is an upward force. For this study, the anchoring conception was a hand pressing down on a spring. The second analogy was a book resting on the spring; the third one was a book resting on a flexible board between two sawhorses; and the fourth one was the target situation, a book resting on the table.

The pretest results show that 40 of the 73 students did not believe that there is an upward force on the book. The researcher classified students’ initial responses into several categories which are: (a) because of gravity there is no upward force (19 students), (b) because a table has no agency for exerting a force (7 students), (c) because the table is not pushing or pulling (5 students), (d) because the table is just in the way and
stable (4 students), and (e) because the book would move up if the table exerted an upward force (4 students). According to the author, students have undergone a deep and far-reaching conceptual change through bridging explanations. The students changed their conceptions from the table as a rigid object to the table as a flexible object. This change in their conceptualization about the table helped them improve their understanding of the upward force on the book exerted by the table.

To explore the students’ anchoring conceptions Clement et al. (1989) conducted a study with three groups of students (17-years-old, 15-years-old, and 14-years-old) who had not yet taken any physics course. The main purpose of the study was to identify students’ anchoring conceptions through a diagnostic test that was composed of 13 multiple-choice questions (static objects: questions 1 to 6, and Newton’s third law in dynamic situations: questions 7 to 13). Students were asked to indicate their confidence in their answers for each question on a scale ranging from 0 (blind guess) to 3 (I am sure). The authors define the anchoring conceptions as “an intuitive knowledge structure that is in rough agreement with accepted physical theory” (p. 555). For this particular study, Clement et al. refer to a student’s correct response and his/her substantial confidence in their solution to the problem as an anchoring example for that student. Several conceptions were identified according to students’ responses on the diagnostics test. For example, 80% of the students answered correctly with high confidence that a spring pushes up on your hand when you press down on the spring and hold your hand still. Similarly, 84% of the students answered correctly with high confidence that a rowboat would move to the left when a person steps out of it to the right. Seventy-four
percent of the students answered correctly with high confidence that a skater pushing another skater to the right would move to the left.

Clement et al. (1989) suggest that anchoring conceptions can be used as essential elements in teaching strategies to overcome students’ misconceptions. However, the authors state that students might refuse to believe that the prediction from the anchoring conception can be applied to the target situation. The authors call these anchoring conceptions brittle anchors. When students transfer surface relationship to the target instead of the key relationship, the authors refer to these anchors as brittle. For example, 96% of the students answered correctly with high confidence that identical carts, pushed apart by a spring suspended between the carts, would move apart at the same speed. However, only 32% of these students said the carts move apart at the same speed for the virtually identical, but slightly asymmetrical situation in question 10 in which the spring was attached to one of the carts (a small extra weight is added to the other cart to make their weights equal again.) Therefore, the authors refer to the symmetrical-carts situation as a brittle anchoring example.

It has to be considered that using analogies and anchoring conceptions may help students with their “initial” understanding of a conception, but they do not necessarily lead to far-reaching conceptual change. In contrast, it can also be claimed that analogies and anchoring conceptions may empower some alternative conceptions. For example, using the spring example does not help students to understand the scientific meaning of force. Students are not changing the ontology (force is a property of matter) attributed to the force concept. In this example, students consider that the force is stored in the spring and this force pushes the hand upward. This reasoning completely contradicts physics -
force cannot be stored. From this analogy, students conceptualize that, by considering the
table as springy, the table stores the force and this “stored” force pushes the book
upward. Although students accept the idea that a table exerts upward force on the book
resting on the table, their reasoning is still non-scientific.

**Anomalous Data**

The most common instructional approach to create dissatisfaction with prior
conceptions is using anomalous data. Using anomalous data refers to presenting students
with evidence that contradicts their alternative conceptions (Chinn & Brewer, 1993). The
basic assumption behind using anomalous data is that students do not accept the new
conception easily until they realize that their alternative conceptions do not work
anymore. Without considering conceptual ecology, students can be expected to give up
their alternative conceptions when they are confronted with anomalous data, but this is
not the case. In their paper on the role of anomalous data in knowledge acquisition, Chinn
and Brewer postulate that students respond to anomalous data in several ways. These
responses are: ignore the anomalous data, reject the data, exclude the data from the
domain of current conception, hold the data in abeyance, reinterpret the data while
retaining current conception, reinterpret the data and make peripheral changes to the
current conception, and accept the data and change the current conception.

Tao and Gunstone (1999) conducted a study with 27 science class students (grade
10) to explore the role of conceptual conflict in fostering conceptual change. A computer
simulation program, Force and Motion Microworld, was developed to match and
confront students’ alternative conceptions regarding the force concept. The computer
simulation program was incorporated into a 10-week physics unit. Students were
assigned in pairs and were asked to accomplish several tasks while they were working on the microworld. These tasks were: (a) make a prediction about the consequences when certain changes were made to the program, (b) explain the prediction, (c) run the program to test their prediction, and (d) reconcile any discrepancy between their prediction and the observation in the microworld. A wide range of data (pretests, posttests, delayed posttests, and interviews) were collected at various junctures during the study. Based on the data analysis the authors asserted, “Conceptual conflict did not always produce conceptual change. For conflicts to lead to change, students need to reflect on and reconstruct their conceptions” (p. 870). The data analysis also showed that students’ conceptual change was context dependent and unstable. Three contexts to analyze the effect of force were identified in the microworld: model car, spaceship, and skydiver. Although students accepted the scientific conception rather easily in the skydiver task, they experienced difficulties in the model car task. The delayed posttest scores also showed that students were apt to regress back to alternative conceptions in a 10-week period of time.

Metacognition

Metacognition, constructivism, and the nature of individual change are three important theories related to science education (Baird, Fensham, Gunstone, & White, 1991). The basic elements of the CCM, conditions for conceptual change and conceptual ecology, inherently require learners to engage in metacognitive activities for a successful conceptual change. Gunstone and Mitchell (1998) emphasize the intertwined nature of conceptual change and metacognition, “the process of recognizing existing conceptions, evaluating these, deciding whether to reconstruct, and reviewing are all metacognitive
processes; they require appropriate metacognitive knowledge, awareness and control” (p. 137). According to Mortimer (1995), students’ awareness of their own profile is essential in the learning process. Awareness leads students to realize the limitations of their conceptual profiles and to evaluate their relative power. As discussed by Stenhouse (1986), the language-game used by “teacher’s science” and “student’s science” is different for many of the conceptions in physics class, especially for basic terms such as “force,” “energy,” and “acceleration.” Students construct the meanings of these concepts from their everyday experiences in their social environment, and many times their meanings are implicit. When students are confronted with a new conception, they might not realize that there is a conflict between their alternative conception and the new conception; instead the new conception might appear meaningless. The learner needs to be aware of the context in which he/she developed his/her alternative conceptions. For example, in Newtonian mechanics, many problems are defined in a frictionless environment. However, students acquire their alternative conception from their daily experiences, which involves friction. Without being conscious about the nature of their alternative conceptions and the scientific conceptions, it is difficult to expect students to experience cognitive conflict.

Linder (1993) suggests that students need to be conscious of their different profiles. Moreover, students need to monitor their cognitive activities, specifically, which profile he/she is transferring for problem representation is essential for the fruitfulness of the new conception. Georghiades (2000) supports the idea that instructional approaches aimed to increase students’ metacognitive capabilities increase the durability and transfer of the new conceptions.
Several studies show that students can be engaged in high-level metacognitive activities. Hennessey (1999) reveals that even younger (grades 1-6) students can be conscious about their own and other’s conceptions. Her students monitored and reported their cognitive processes while they were learning new concepts. Regarding conceptual change, Hennessey also found that her students acquired the ability to monitor the status of new conceptions in their conceptual framework. They could successfully use the terms such as intelligibility and plausibility to express the status of their understandings of the new conceptions. Similarly, the work of Beeth (1998) supports that students can acquire high-level metacognitive abilities such as speaking about their conceptions and cognitive processes. Baird (1986) conducted a study with grade 9 and 11 students and found that training for enhanced metacognition helped students gain greater control over their learning. It is not an easy task to get students involved in metacognitive activities and it is not an achievement that can be gained in a short period of time either. As White (1993b) states,

It takes so long to develop metacognition, it is not an enterprise for dilettantes. It has to pervade the teacher’s professional life. A necessary condition for this is ownership. Teachers, and if at all possible the students also, must feel that this is their enterprise. Ownership implies opportunity to contribute, to suggest new procedures, to alter what is being done. (p.13)

*The Nature of Alternative Conceptions*

There are several views regarding the nature of alternative conceptions (NAC). Most of the studies based on exploring the NAC are in the domain of physics. These
views are based on the differences between scientific conceptions and alternative conceptions. Because the nature of scientific conceptions differ among different domains, it might not be appropriate to generalize these views across different domains.

Particularly three important views regarding the NAC are considered in this chapter: “knowledge as ontological categories,” “knowledge as fragmented pieces,” and “knowledge as theoretical structures.”

Knowledge as Ontological Categories

Chi and Slotta (1993) based their interpretation about the NAC on the ontological nature of entities in the world and the metaphysical nature of scientific concepts. Chi and Slotta propose three ontological categories for the entities in the world. According to their characteristics, different entities fall into different ontological categories, which are “Matter,” “Processes,” and “Mental States.” There are also several subcategories set in each major category such as “natural kind” and “artifacts” within Matter; “procedures,” “events,” and “constrained based interaction” within Processes; and “emotional” and “intentional” within Mental States.

The metaphysical nature of many physics concepts falls into the Processes category, more specifically “constrained based interaction.” Chi et al. (1994) identify several ontological attributes of the category of “constrained based interaction” such as no beginning and end, no progression, acausal, uniform in magnitude, simultaneous, static, and on-going. Gravitational force, electrical current, heat, and light are some examples of physical concepts belonging to this category. Based on these categories, Chi et al. interpret the nature of students’ alternative conceptions as misclassification of physics concepts according to their ontological characteristics. Several studies (Reiner,
Chi, & Resnick, 1988; Reiner, Slotta, Chi, & Resnick, 2000) show that students tend to consider several physics concepts such as heat and force as examples within the matter category. Students interpret these concepts either as material substances or properties of a material substance.

Chi et al. (1994) attribute the difficulties in students’ learning of certain scientific concepts to the mismatch or incompatibility between students’ ontological categorization of concepts and the true ontological category to which the concepts belong. Chi et al. consider the example of electrical current. In many cases, flowing water is used as an analogy to explain the electrical current. This analogy stimulates students to put the electrical current concept into the “matter” category more specifically the “liquid” subcategory. Several studies show that analogies and exploratory models seem to be mediator tools to increase the status of the new conception, especially intelligibility. However, these analogies might create several alternative conceptions. For this specific electrical current example, students might conclude that “it can be stored in the battery” or “it can be used up”. According to Chi and Slotta (1993), a successful conceptual change can be achieved by helping students change the wrong ontology to a correct one attributed to a concept.

Several studies in the alternative conceptions literature support the idea that students assign wrong ontological attributes to some physical concepts. For example, Brown and Clement (1987a, 1987b) administered a multiple-choice diagnostic test to high school students and conducted interviews with them. It revealed that students conceptualize the force concept as a property of single objects within the matter category. For instance, during the interviews every one of the five students responded confidently
that a moving cue ball exerts more force than the stationary ball when they collide. The common explanation for students’ responses was that force from the moving ball would be “transferred” to the stationary ball.

Similarly, Lee and Law (2001) administered a written test and conducted interviews with elementary school students to identify their alternative conceptions about electric circuits. The analysis of interview protocols showed that most of the students with lower performance on the written test interpreted the current concept as matter. The terms such as “comes out,” “used up,” and “divided into” were considered as evidence for students’ ontological attributes for the current concept. However, students with higher test performance tended to consider the whole circuit as a system and interpret current as “constrained based interaction” in their reasoning about circuit phenomena.

Knowledge as Fragmented Pieces

According to diSessa (1988), intuitive knowledge or the NAC are large amounts of fragmented knowledge abstracted from common and relatively primitive experiences and provide the basis for more abstract and higher level reasoning about physical processes. DiSessa defines these primitive experiences as phenomenological primitives (p-prims), which are pieces of knowledge that need no explanations. For example people do not try to explain why an object drops when it is released; it is just regarded as an expected event. diSessa (1993) interprets the organization of intuitive knowledge as a weak coherent structure of p-prims.

According to this interpretation, many of the alternative conceptions are derived from p-prims. P-prims are considered as an intuitive equivalent of physical laws; they are not themselves explained (just regarded as an expected event), but they explain
other phenomena (diSessa, 1993). P-prims are activated in appropriate circumstances according to p–prims cuing priority; perceived context cues the recognition of the p-prim. Although experts have the ability to reduce the new situation or problem to a few core theoretical ideas by analyzing the circumstance successfully, novices do not. By examining the differences regarding cognitive processes between novices and experts in physics, diSessa claims, “learning physics can be viewed in significant degree as building a gradient between phenomenological and fundamental by reorganizing existing phenomenology” (p. 108).

Knowledge as Theoretical Structures

The interpretation of the NAC by Vosniadou (1994) is based on two distinct categories: a naïve framework theory of physics and various specific theories. A naïve framework theory of physics refers to certain fundamental ontological and epistemological presuppositions such as continuity, solidity, gravity, and inertia, which begin to be constructed in infancy.

This naïve framework theory of physics has a substantial role in the process of acquiring knowledge about the physical world. Vosniadou (1994) emphasizes the similarity between students’ naïve framework theory of physics and research programs (Lakatos, 1970) or paradigms (Kuhn, 1970) defined in the history of science. Like the paradigms constraining the development of scientific theories, students’ naïve framework theory of physics constrains their knowledge acquisition.

The second category is specific theories, which are constructed through observations, experiences, or information presented by the culture under the constraints of the naive framework theory. “A specific theory consists of a set of interrelated
propositions or beliefs that describe the properties and behavior of physical objects” (Vosniadou, 1994, p. 47). Vosniadou clarifies the distinction between a specific theory and a naïve framework theory with an example of the heat concept. A specific theory is that “hotness can transfer from one object to another which is less hot by direct contact.” The naïve framework theory constraining this specific theory is that “hotness is a transferable property of physical objects.” As expected, her studies show that revision of naïve framework theories are much more difficult than revision of specific theories.

Several studies conducted by Vosniadou and her colleagues (Ioannides & Vosniadou, 1991; Samarapungavan & Vosniadou, 1989; Vosniadou & Brewer, 1992; Vosniadou & Kempner, 1993) with preschool and elementary school students are provided as evidence supporting her theoretical framework regarding the NAC. These studies include the concepts of heat, the shape of the earth, day/night cycle, and force. The common characteristic of these studies is to stimulate students to construct and reveal their mental models for the questions asked by the researchers. In this context, mental model is defined as “a special kind of mental representation, an analog representation, which individuals generate during cognitive functioning” (Vosniadou, 1994, p. 48). In their studies, the researchers prefer to use generative questions, which do not directly refer to the concepts gained through instruction. For example, rather than just asking “What is the shape of the earth?” the researchers prefer to ask “If you walked and walked for many days in a straight line, where would you end up?” to stimulate students to reveal their mental models concerning the shape of the earth instead of repeating what they have memorized through social interaction or formal education. Students’ mental
models give important clues regarding their naïve framework theory of physics, which constrain their responses to the questions.

The findings from these studies support Vosniadou’s (1994) assertion that many of the alternative conceptions are constructed by individuals’ attempts to interpret the new situations or problems within an existing naive framework theory, which is contradictory to scientific view. Therefore, Vosniadou suggests that students’ framework theories and their power in the construction of alternative conceptions should be considered in instructional designs.

McCloskey (1983) also interprets the NAC as naïve theories without making any distinction such as framework theories or specific theories. His assertion is based on the similarities between students’ conceptions and scientific ideas in the history of science. His study was conducted with 48 undergraduate students at the Johns Hopkins University. Subjects were asked to respond to 13 non-quantitative problems concerning the behavior of moving objects. Each problem included a diagram and subjects were asked to predict and explain the motion of the object demonstrated in the diagram. After the analysis of students’ responses to the problems, 13 students were interviewed. The author claims that students’ naïve theories about force are similar to impetus or impressed force theory discussed by Philoponus in the 6th century and developed by John Buridan and others in the 14th century. For later years, the author refers to Galileo’s interpretation about the projectile motion. Galileo states,

The body moves upward, provided the impressed motive force is greater than the resting weight. But since that force... is continually weakened, it will become so
diminished that will no longer overcome the weight of the body and will not impel the body beyond that point. (p. 317)

During the interviews, students’ explanations regarding projectile motion are similar to Galileo’s interpretation. For example one of the subjects states,

The ball when it was first thrown was provided with a certain amount of force…What’s happening is that the force is basically being counterbalanced by gravity, and at this point (when it is going up) the upward force is still stronger than gravity, while here (at the top) they are both equal and here (when it is going down) gravity becomes stronger. (p. 308)

This example about projectile motion also supports Vosniadou’s (1994) interpretation about the NAC. It is clearly seen that students’ theory about force (naïve framework theory) constrains their interpretation about projectile motion (specific theory). Students conceptualize the force as a property of the object and this misconception does not let them construct a correct representation for projectile motion.

Arguments Against Expecting a Change

After the implementation of the CCM in instructional designs, several arguments appeared regarding the nature of expected change in students’ conceptions. The main emphasis of these arguments is the context in which learning takes place. In this section three important arguments will be reviewed in the following order: “conceptual appreciation,” “conceptual profile change,” and “situated cognition.”

Conceptual Appreciation

Based on several philosophers’ (Berger & Luckmann, 1967; Schutz & Luckmann, 1974) and educationalists’ (Brauner, 1988; Solomon, 1983) assertions about
the nature of knowledge, Linder (1993) proposes “conceptual appreciation” rather than “conceptual change.” According to these assertions, people construct different domains of knowledge and different modes of perception. “In particular, it is argued that people are continually being socialized into a whole social repertoire of knowledge and that such socialized knowledge cannot ever, by its nature, be extinguished” (Linder, p. 294). Linder argues that without defining a context, it is not reasonable to claim that a conception is appropriate or legitimate; therefore, more emphasis should be given to enhance students’ abilities to distinguish the conceptualization in a different context rather than to change students’ existing conceptions.

One of the most important purposes of science is to produce general principles, which can be applied to a wide range of situations. The more general the principle is the more complicated it is (compare the quantum physics with Newtonian physics). Even physicists do not attempt to solve every problem according to the principles of quantum physics because there is no need to use a more general principle when there is a simple working principle in that context. For example, Newtonian physics contradicts contemporary physics - relativity and quantum physics. However, it works almost perfectly when the appropriate context is defined (e.g., slow moving macroscopic particles or objects.)

In the same manner, most of the intuitive knowledge or alternative conceptions work perfectly in our everyday environment. Let’s consider two statements, the first one is that “in our environment a moving object does not go far without applying a force” and the second one is that “an object in motion tends to stay in motion with the same speed and in the same direction unless acted upon by an unbalanced force.” The first statement
is intuitive knowledge and the second one is Newton’s first law. Although both conceptions are valid in its defined context, Newton’s second law is more general and more complicated. Therefore, even people who know and understand Newton’s first law prefer to use intuitive knowledge because it is less complicated and valid in the everyday context. According to Linder (1993), the main problem is that students cannot develop a meaningful relationship with the new context introduced in the physics classrooms. In other words, they cannot make distinctions between the context in which their prior conceptions are developed and the context in which physical concepts are defined.

Linder (1993) points out another important issue regarding fruitfulness of the conceptualization: “In science, appropriateness of conceptualization requires a context, for it is the context that sets the boundary conditions regarding experimental confirmation, in other words, the fruitfulness of the conceptualization.” (p. 296)

**Conceptual Profile Change**

Similar to Linder’s (1993) arguments, Mortimer (1995) also focuses on different ways of thinking in different domains. Mortimer suggests a new model, “conceptual profile change,” by considering that alternative conceptions do not disappear; instead, individuals even experts keep using their alternative conceptions in their daily life. Mortimer defines the conceptual profile as ontological and epistemological features attributed to a concept. The basic difference between experts and novices is that experts are conscious of their different conceptual profiles and can shift from one profile to another according to the defined context. According to the nature of concepts, there might be several zones of conceptual profile. Mortimer clarifies this assertion with an example, the concept of matter. Possible zones of conceptual profiles are a realist view of
matter (as something continuous), a primary atomistic view (matter as constituted by particles in motion in empty space), developed atomistic view (the atom as a system of sub-particles), and a quantum view (the atom as a system of quantum objects described by mathematical models). Although the last two zones of conceptual profile refer to scientists’ profiles, scientists have also other zones. In their everyday life, scientists also use matter as something continuous but when they are confronted with problematic situations they shift to a scientific profile such as a developed atomistic view or a quantum view.

Mortimer (1995) suggests that more emphasis should be given to make students conscious about the existence of different profiles according to different contexts. This suggestion implies that introducing new concepts means creating a new profile for that concept because a prior profile (or alternative conception) will not disappear. Therefore, special attention should be given to help students be conscious about their different profiles and help them gain ability to use appropriate profiles in appropriate contexts.

*Situated Cognition*

There are two emphases underlying the assertions of situated cognition in a learning situation: context and culture in which learning is situated. Similar to the interpretations about different language-games used by “teacher’s science” and “student’s science” by Stenhouse (1986), the different contexts assumed by “teacher’s science” and “student’s science” are the focus of attention in situated cognition. According to Ueno (1993), in learning Newtonian physics, it is not possible to produce a conceptual change through falsification or equilibration of alternative conceptions because students’ cannot come to know the metacontext of Newtonian physics with the presentations of anomalous
data. Students have their own implicit metacontext in which the considered concept is nested. For example, although the Newtonian physics considers a frictionless environment, students’ metacontext does have frictions for most of the concepts related to Newtonian physics. From the situated cognition point of view, Ueno suggests that for a successful conceptual change “learning physics is not to abandon the metacontext of everyday discourse but to clarify the contrast between the metacontext of the two kinds of discourse” (p. 247). Ueno attributes the robustness of alternative conceptions to the lack of appropriate communication between everyday community and scientific community.

Within the tradition of situated cognition, Hallden (1999) also emphasizes the importance of contextualization to understand the difficulties students experience in their acquisition of a scientific concept:

The problem is not how to bring about a conceptual change, but rather to know what characterizes the situation in which the students entertain their common-sense descriptions and explanations; consequently, the educational problem is how to create a situation where the appropriate scientific ideas come to play.

(p. 53)

Hallden’s (1999) study supports the assumption that when a student refers to her/his alternative conceptions to solve an encountered problem, it does not necessarily mean that the student has not acquired the underlying scientific conception for the solution of the problem. In other terms, “it is not self-evident that the scientific concepts will prevail” (p. 64). Hallden asked the following question (generated by Kahneman and Tversky, 1982) to the students majoring in psychology.
Linda is 31 years old, single, outspoken, and very bright. She majored in philosophy. As a student, she was deeply concerned with issues of discrimination and social justice, and also participated in anti-nuclear demonstrations. Which one of the following two statements about Linda is the more probable one? (i) Linda is a bank teller or (ii) Linda is a bank teller who is active in the feminist movement.

Students’ reasoning in their choice reveals that the very problematic issue in their response cannot be reduced to the question of whether students acquired the scientific conception or not. Responses reveal that even the students who acquired scientific conceptions are apt to activate their alternative conceptions for their choices. For example, one of the students gave his/her rationale,

First I thought (i), according to the rules for determining the probability of a true statement (the conjunction rule states that the probability of a conjunction A and B cannot exceed the probability of either A or B alone), but then I thought I was supposed to draw conclusions from the text describing Linda and thus I choose (ii). Now, however, I realize I was wrong. (p. 57)

A more radical study was conducted by Clement (1994) to investigate the role of intuitive knowledge among expert problem solvers (e.g., advanced doctoral students or professors in technical fields). Clement’s argument is against the common supposition that while the knowledge used by experts in science is abstract, the knowledge used by novices is concrete. Clement hypothesizes that experts “possess knowledge structures called elemental physical intuitions that are concrete and self-evaluated, have modest generality, and stand without further explanation or justification” (p. 209). Clement
provides several examples from think-aloud transcripts supporting this hypothesis. One of the problems asked to the participants is as follows:

A weight is hung on a spring. The original spring is replaced with a spring; made of the same kind of wire, with the same number of coils, but with coils that are twice as wide in diameter. Will the spring stretch from its natural length, more, less, or the same amount under the weight? (Assume the mass of the spring is negligible compared to the mass of the weight.)

Why do you think so? (p.207)

The response of a physicist clearly shows that his solution approach relies on direct application of physical intuition rather than scientific principles.

S1: You don't have to know any formulas to see that it's; -Why would I bet that it’s more? [the stretch of the wider spring] Not because I’ve analyzed the physics. Because when I sit there and see that spring, and now I take the same wire and make a big spring like that and put my weight on it, God almighty! Of course it goes way down. You know. How could it do otherwise?

S2: So that is just a matter of almost uh-I’ve wound springs you know in the shop, and that’s a seat-of-the-pants feeling I would trust beyond any of it. So if you asked how much will I bet uhh, on the answer that it stretches more than the same length, I would bet a thousand to one. (p. 208)

This chapter began with the review of the CCM and then several instructional strategies inspired by this model were outlined. In the next section, different interpretations about the nature of alternative conceptions were provided. Finally, the
arguments against expecting a replacement in students’ conceptual frameworks were presented. The review of the literature provided in this chapter reveals that there is a consensus among researchers that learning is a change process in an individual’s cognitive structure. Although the CCM stands as a way of explaining this change process, there are several arguments criticizing the nature of the change proposed by this model. In addition to these arguments, the failure of the instructional strategies inspired by the CCM intrigued this researcher to inquire empirically whether or not the individuals who acquired scientific conceptions have replaced their alternative conceptions. Similar to many of the studies in this particular domain, the nature of this inquiry requires a qualitative methodology. In the following chapter the methodology of this study is described.
CHAPTER 3

METHODOLOGY

In the first chapter, several arguments against expecting a replacement of alternative conceptions with scientific conceptions were addressed and the rationality of the coexistence of multiple conceptions was discussed. These discussions led to three main research questions:

1. Do individuals keep their alternative conceptions after they have acquired scientific conceptions?

2. Assuming that individuals who acquired scientific conceptions also have alternative conceptions, how are these different conceptions nested in their conceptual structure?

3. What kind of knowledge, skills, and reasoning are necessary to transfer scientific principles instead of alternative ones in the construction of a valid model?

The nature of these questions requires describing an individual’s knowledge structure and cognitive processes. More specifically, this study is interested in conceptual knowledge and its transfer in problem-solving situations. In this context, two kinds of conceptual knowledge, alternative and scientific, are under investigation. From a methodological standpoint; however, it is important to explicitly define what conceptual
knowledge is, so we can correctly observe and interpret corresponding scientific and alternative conceptions. For this purpose a framework was developed in the first chapter and three facets of conceptual knowledge were identified as elements, principles, and models.

The core objects of this study are these three facets of conceptual knowledge and their function. Therefore, the design of the study was developed in a way that two dimensions of these facets could be identified in terms of alternative and scientific conceptions. The research questions of this study inherently required participants who had already acquired scientific conceptions in order to investigate the coexistence of alternative and scientific conceptions. Nevertheless, it was also necessary to establish a reference frame for alternative conceptions. For this purpose, another group of participants whose scientific knowledge was minimal in the defined domain was identified as a reference frame.

In terms of data the collection procedure, individually conducted problem-solving sessions were considered to be the most efficient way of collecting data to satisfy the purpose of this study. Problem-solving sessions had a potential to provide a unique environment to observe all facets of conceptual knowledge and their function throughout the participants’ verbal reports. According to Ericsson and Simon (1993), two forms of verbal reports, “think aloud” and “retrospective” reports, are the closest reflection of the cognitive processes. Although there are some arguments about the possible effect of verbalization on cognitive processes, the argument put forth by Ericsson and Simon on this issue was taken as an assumption for the data collection procedure of this study. These theorists assume that “when the cognitive processes attend to or activate a structure
in the memory that is orally encoded, then this structure can at the same time be vocalized overtly without making additional demands on processing time or capacity” (p. 63).

The general procedure for think-aloud method is that the subject is asked to talk aloud while she/he is solving a problem, and this request is repeated if the subject remains silent for a while to encourage her/him to tell what she/he is thinking at that moment (van Someren, Barnard, & Sandberg, 1994). In the case of retrospection, subjects are questioned afterwards to report on the cognitive processes they performed during a problem-solving situation (Ericsson & Simon, 1993).

After this brief overview of the general methodology, the descriptions of the participant selection, the problems used in the problem-solving sessions, and the procedure for collecting and analyzing data are presented with details in the following sections.

Participants

Two groups of participants, physics group (P-group) and non-physics group (NP-group), were selected for this study. The following criteria were established for the selection of the P-group: (a) had at least an earned B.S. degree in physics and (b) was not engaged in any formal activities of teaching or learning physics during the period of data collection. This second criterion was established to minimize the participants’ automatic procedures in problem-solving activities. It was assumed that an individual who had a strong physics background and was spending a considerable amount of time studying physics in the period of data collection would likely access a well-practiced schema in the problem-solving sessions, which would block the intervention of intuitive knowledge and
minimize the data collection. The only criterion for the NP-group was that they did not have any college level physics study in their academic background.

A list of 30 individuals satisfying the above criteria was generated from Turkish graduate students enrolled in the College of Education at The Ohio State University. They were contacted individually (either by phone, e-mail, or face-to-face) and informed about the nature of the research (see Appendix A). Background information related to studying physics in both high school and university level (see Appendix B) was collected from the individuals who agreed to participate in the study. According to their academic background, five individuals were selected for each group.

The only reason for recruiting participants among Turkish students was that the native language of the researcher of this study is Turkish. Because the data collection procedure was based on verbal reports, it was essential to maximize the communication between the researcher and the participant during the problem-solving sessions. It was highly possible for participants to use different kinds of analogies and metaphors chosen from daily life experiences in their attempt to reach a solution. These cognitive artifacts have their own meanings in their own cultural settings. The researcher should be a part of these cultural settings to create a meaningful communication with the participants. Therefore, the selection of participants from the Turkish community satisfied these concerns.

Problem-Solving Packet

A review of the relevant literature revealed that students are inclined to activate their alternative conceptions on mechanics problems. Therefore, using mechanics problems was a productive way to collect the necessary data for this study. Ten potential
mechanics problems were identified in the initial phase of this study. In the selection of these problems, the following criteria were established. The problems (a) should be embedded in everyday-related situations, (b) should be interesting and challenging to the participants so as to motivate them to come up with a solution, and (c) should not require complex algebraic manipulations. Six final problems were selected through piloting of these potential problems. A list of six problems is provided in Appendix C.

Data Collection Procedure

The data collection procedure of this study was based on think-aloud and retrospective methods conducted with each participant in problem-solving sessions. Although the same problems were asked in the problem-solving sessions, the procedure was different for P-group and NP-group. In the following sections, the purpose and the procedure of data collection for each group is presented.

Procedure for the NP-Group

The purpose of collecting data from the NP-group was to identify possible alternative conceptions specific to the problems in the problem-solving packet. Based on the conceptual framework developed for the notion of “conception” in the Chapter 1, three facets of alternative conceptions (e.g., elements, principles, and models) were described throughout the problem-solving sessions. The following procedure was planned for this purpose.

Each participant was met individually and told that they would be given several problems to solve. At the beginning of the session, the participant was informed that she/he would be asked to “think aloud” while solving a problem. A brief explanation about the think-aloud process was provided to the participant and then they were given
the opportunity to practice it on a sample problem. The problem-solving session did not begin until the participant felt comfortable with the task of thinking aloud.

After the practice on a sample problem was completed and the recording equipment was tested, the participant was asked to read the first problem and to think aloud while solving the problem. After the participant finished solving the first problem, several retrospective questions were asked to obtain further information about the conceptual knowledge that she/he brought into the problem situation. The first purpose of these retrospective questions was to collect information about how the participant conceptualized the elements (e.g., force, acceleration, and gravitation) implicitly or explicitly embedded into the problem. The second purpose was to collect information about the nature of the principle or principles the participant transferred into the problem situation.

The same procedure was followed for the rest of the problems. The instructions and the sample problem are presented in Appendix D.

_Procedure for the P-Group_

The core argument behind this study is the coexistence of alternative and scientific conceptions; consequently, the main subjects of this study are the individuals who have already acquired scientific conceptions. However, without the identification of alternative conceptions, the data collection procedure with the P-group would be ambiguous, especially in the phase of retrospective questioning. Therefore, data collection from the P-group began after analyzing the data collected from the NP-group. The following procedure was implemented for the P-group.
The same instructions and practice provided to the NP-group were also provided to each participant of the P-group. After this, the participant was asked to read the first problem and to think aloud while she/he was solving the problem. When the participant reached a solution, the first retrospective question was about her/his immediate response to the problem. Because the structure of the problems highly encouraged the individual to come up with an immediate answer, it was very likely that the participant’s immediate response and final response might differ. It was assumed that the conceptual knowledge (elements and principles) used for immediate response and final response might differ. Throughout retrospective questions, verbalization of the participant’s conceptual knowledge, which they brought into the problem situation, was sought if it had not been verbalized with details while the participant was thinking aloud. If it was found that enough evidence about the existence of multiple conceptions in terms of elements and principles had been revealed, the participant was encouraged to verbalize their rationale for making a decision in favor of any particular element or principle.

Data Analysis

All of the problem-solving activities of participants including verbal statements, writing equations, and drawing diagrams were transcribed. The protocol was divided into segments for the purpose of analysis. Ericsson and Simon (1993) suggest that boundaries of phrases are usually marked by pauses. In keeping with these researchers, the segmentation was based on these pauses and the linguistic structure in the participants’ verbalizations. These segmented protocols comprised the raw data for this study.

It is important to distinguish between raw data and protocol codes. Protocol codes are the data from which researchers make inferences; however, coding schemes should
not be contaminated with the driven theory (Ericsson & Simon, 1993). Otherwise, any inferences taken from the protocol analysis would be unreliable. However, Ericsson and Simon also argue the impossibility of collecting and coding data without an existing theory.

It cannot mean that data are collected and encoded without regard to existing theory. We have already seen why that cannot and should not be done. A single protocol is not an island to itself, but a link in a whole chain of evidence, stretching far into the past and future, that gradually develops, molds, and modifies our scientific theories. It needs to be processed with full attention to these links. (p. 280)

Considering these statements as a criterion for the reliability of the protocol coding, protocol statements were coded according to the kinds of conceptual knowledge used and the types of processes performed. Although these two general categories were not directly based on any specific theoretical model, it was necessary to define a theoretical theme describing which cognitive processes would occur and in which order they would occur. The data collection procedure of this study was set in the problem-solving sessions; therefore, a theoretical theme should provide a general mechanism for an individual’s problem solving. In the educational field of study, the dominant theoretical framework on how individuals solve problems has been provided by the information-processing paradigm. According to the information-processing paradigm, the general mechanism of problem solving is that an information processor “takes a natural-language problem statement, translates it into an internal representation on which it can operate, and then outputs the result” (Maloney, 1994, p. 328). These two general
actions in this mechanism of problem solving, internal representation and operation on this representation, constructed a framework for the data collected throughout problem-solving sessions.

The research questions of this study were directly related to the actions verbalized by the participants in the problem-solving sessions. Therefore, internal representations and operations would be two of the main categories of protocol coding. In the context of this study, internal representation would refer to how individuals conceptualized the elements implicitly or explicitly embedded into the problem statements. In this context again, the operators were knowledge structures transferred into the problem situation to reach a solution. These knowledge structures were labeled as principles. The sub-categories of elements and principles were defined according to emerging patterns from the participants’ verbalizations of their actions in problem-solving sessions.

Another main category was based on the assumption that individuals (P-group) who acquired scientific elements and principles also had alternative elements and principles. This assumption had led us to consider how these different conceptions would be nested in individuals’ conceptual structures and how these conceptions would be activated appropriately. There must be several kinds of knowledge, skills, or strategies associated with the storage and activation of specific conceptions. It was intended that these executive factors would be verbalized throughout think-aloud and retrospective questioning. The emerging patterns from these verbalizations were categorized accordingly.
Validity Issues

Researchers in the field of qualitative studies (e.g., Lincoln & Guba, 1985, 2000; Moschkovich & Brenner, 2000) propose several strategies to establish the trustworthiness of the procedures for data collection and analysis. Four types of strategies used to increase the trustworthiness of the current study were as follows: member checking, negative case analysis, prolonged engagement, and peer debriefing.

Member Checking

Throughout the whole problem solving session, the researcher always checked with the participants whether the researcher’s interpretation from their verbal reports is parallel with what they actually meant. Whenever a conflict occurred, the participants were given the opportunity for further explanations.

Negative Case Analysis

One issue with data analysis is the researcher’s potential bias to seek what he wants to see as a result of an investigation. Negative case analysis is a way to eliminate this concern by seeking counter examples of what has already been found as result of the investigation. In this particular study, several negative statements of the results were generated for this purpose. The testable forms of these statements are as follows:

1. Is there any evidence that a participant does not refer to either reasoning by mental simulation or semiformal reasoning throughout the whole problem solving session?
2. Is there any evidence that reasoning by mental simulation and formal reasoning were intertwined?
3. Is there any evidence that semiformal and formal reasoning were compartmentalized?

The re-analysis of the available data did not provide any evidence to come up with a confirmatory answer for any of these questions.

**Prolonged Engagement**

Providing a comfortable environment between the researcher and the participants is an essential factor for any kind of data collection procedure. Especially, the inquiries supposed to observe cognitive processes require the participants to be as comfortable as possible to reveal anything passing through her/his mind without any hesitation. It is usually difficult to construct such an environment between individuals who hardly know one another. Therefore, the researcher of this study tried to select participants from the individuals who had known the researcher for at least six months. Except for one participant (P4), all the participants satisfied this concern. To provide the same condition with P4, the researcher made contact with him immediately after he agreed to participate in the study and arranged several times to communicate and get to know him before the data collection. Although the period of data collection procedure with each participant was not more than a few hours, prolonged engagement with participants previous to data collection assured that this process was carried out under the circumstances of mutual comfort and trust.

**Peer Debriefing**

A colleague of the researcher who had special interest in conceptual knowledge and cognitive processes was asked to examine the procedures of data collection, analysis,
and conclusions. The following issues were specially outlined by the researcher for the examination:

- Is there any case that the researcher purposefully lead the participants to make them say what he wants to hear?
- Is there any loss of meaning in the translations?
- Are the categories generated by the researcher meaningful?
- Do the examples given by the researcher load to described categories?
- Is there any detachment from the actual context in the extracted quotations?
- Are the conclusions supported by data?
- Is there any other issue that you notice, which might significantly decrease the reliability or validity of the study?
- Do you have any recommendation to increase the quality of the study?

After the examination of raw data, analysis, and conclusion, she reported that there was no significant problem for the issues asked by the researcher. However, she provided several recommendations such as increasing the number of examples provided in response to the third research question and using more table and figure representations to make several arguments easier to understand.

In this chapter, the description and the rationale of the methodology were provided. Two groups of participants were selected and the data collection procedures were based on think-aloud and retrospective questioning. To increase the trustworthiness of the study several strategies, such as member checking and peer debriefing, were used. In the following chapter, the analysis of the data is provided.
CHAPTER 4
ANALYSIS OF DATA

In this chapter, an analysis of data collected through problem-solving sessions is presented. To make the logic of the analysis clearer this chapter is divided into three broad sections. The first section includes the analysis of data collected from the non-physics group. There are five cases in this section and each case is analyzed separately. The purpose of this section is to construct a reference frame for the rest of the study by presenting a general picture of the participants’ conceptually loaded (e.g., elements, principles, and models) behaviors. As discussed in the introduction chapter, a great dispute rests largely on an ambiguity in the nature of “alternative conceptions.” Parallel with the argument of the whole study, data analysis of this section seeks to understand what kind of reasoning and knowledge structures lead participants to alternative models. As demonstrated in Figure 4.1, more attention is given to the process rather than listing the participants’ so called misconceptions.

Figure 4.1: The purpose of analysis of data collected from the non-physics group.
The second section includes the analysis of data collected from the physics group. There are also five cases in this section and each case is analyzed separately. The purpose of this section is to present a context for the data collected from the physics group. This section can be considered as an intermediate stage leading to the research questions.

In the third section, the focus of analysis is given to address the research questions. This section consists of the analysis of data collected from the physics group by consistently referring to the reference frame outlined in the first section. Data is analyzed purposefully by selecting the specific instances from the problem-solving sessions corresponding to each question.

Before entering into detailed analysis, it is necessary to provide a preview about different processes for reasoning noticed in participants’ verbal reports across the cases. This is because the most explicit pattern of behavior, which was noticed immediately after a general overview of the data, is that the ways the participants reason provide essential insights about the structure of conceptual knowledge and the construction of a model. Three types of reasoning commonly used throughout the problem-solving sessions were categorized as “reasoning by mental simulation,” “semiformal reasoning,” and “formal reasoning”

1. Reasoning by mental simulation: A participant solves a problem by mentally simulating her/his previous experience or observations similar to or the same as the situation described in the problem statement. In this way, she/he tries to predict the consequence of an action. There is almost no interpretation attributed to the corresponding experience or observations. Although there are different levels of interpretation, in the context of this study “interpretation” is used in its
simplest form: perceiving the regularities and formulating principles about how things behave or work in nature.

2. Semi-formal reasoning: A participant solves a problem by referring to an alternative principle or principles, that have already been constructed by the participant by making interpretations related to her/his previous experience or observations. The construction process of these principles refers to the perception of regularities in nature — repeatedly observed or experienced patterns are expected to happen in a similar way.

3. Formal (or scientific) reasoning: A participant solves a problem by referring to a formal system of conceptual structures. In this process of reasoning, “a formal system” refers to the domain specific knowledge structure of physics with well-defined elements and principles.
Individual Cases of the Non-Physics Group

The participants in the non-physics group are referred to as NP1, NP2, NP3, NP4, and NP5. Although each case was analyzed separately, for the sake of clarity and simplicity special focus was given to the shared patterns captured across the cases. Because the problem-solving sessions were originally intended to probe individuals’ cognitive processes and knowledge structures, this section includes the descriptions of participants’ reasoning in model construction and conceptual knowledge (elements and principles) they transferred into the problem situations. These descriptions intended to be more data driven than theory driven by providing direct descriptions of what happened during the problem-solving sessions. However, the necessity of putting these descriptions into categories required some level of interpretation.

The Case of NP1

NP1 was a female Ph.D. student at the College of Education. She had majored in psychology in college. Because she did not take any physics course either in high school or university, her attempts to solve problems provided detailed insights about her pure intuition, which was not contaminated with domain specific knowledge of physics.

Reasoning. One obvious behavior noticed throughout the problem-solving session was NP1’s consistent reference to mental simulations in her responses. Although the reasoning by mental simulation was dominant throughout the whole problem-solving session, she also used semiformal reasoning on several occasions. The following quotations exemplify NP1’s reasoning by mental simulation while she was giving explanations for the path of the ball after the string breaks (second problem).
NP1: Right now this scene comes into my mind: athletes are throwing something in Olympic games. What was it? [Pause]

R: Hammer?

NP1: Yes, a hammer came into my mind. They are swinging the hammer repeatedly and then they release it. The athlete throws the hammer at some point and the hammer goes in straight line. Therefore, this ball also should go in a straight line.

Although she was sure, based on this mental simulation, that the ball would follow a straight line she could not decide about the direction of the ball. The following quotations provide another example of reasoning by mental simulation that NP1 used for making a decision. However, she was an actor instead of an observer in this case. Her explanations are for the third problem. She was trying to find the path of the ball after the kick.

R: What do you think if the ball was moving very fast?

NP1: First it would shake and lose its balance. It would be dragged a little in its original direction [pause] maybe not in the exact original direction. It would be distracted more or less from the original direction according to the intensity of your kick but it would be still a straight line. If it is coming too fast, its speed decreases a little. However, if you kick the ball too hard then it goes wherever you want it to go.

R: What makes you think in this way? Based on what are you thinking in this way?
NP1: Nothing. Actually, this is the picture in my mind. I am imagining that I am doing that [kicking a moving ball] and I am trying to visualize what would happen next.

Although NP1 was inclined to reason by mental simulation, she also used semiformal reasoning when she was able to put the problem situation into a conceptual framework. The following quotations are NP1’s explanations for the fourth problem. She was sure that the full bottle drops faster than the empty one. The interesting point in her behavior is that although she could have easily answered the question by referring to her mental simulations as she did in the preceding examples, she preferred to use semiformal reasoning in this situation. Her reasoning is framed by an alternative principle she had already formulated in a way that “the heavier an object, the harder it is pulled.”

NP1: The full one drops faster because it is heavier: gravitation has more effect on the heavier one. In other words, gravitation pulls the full one harder than the empty one. The heavier the object, the harder it is pulled.

R: Do you mean gravitation pulls the full one harder?

NP1: Actually, the gravitation does not pull more. The gravitation is the same for everything. Let me think about it again [pause]. There is more in heavier one to be pulled. Gravitation may pull more but I do not believe that. I think gravitation is constant. But, it is also an alternative idea. It seems to be constant but its effect is changing. It depends on the material. Because the full one is heavier — it is pulled more. Because it is heavier it is more prone to gravitation.
Elements and Principles. As it has been seen from NP1’s explanations when she reasons by mental simulation she does not refer to any particular elements or principles. It is quite obvious that mental simulation refers to “uninterpreted” observations or experiences. However, when NP1 shifts from mental simulation to semi formal reasoning the function of elements and principles enters into the equation.

The following quotations are good examples for both NP1’s shift in her reasoning and the role of elements and principles. Preceding these quotations, NP1 was looking for an answer for the path of the ball asked in the second problem. She used the reasoning by mental simulation for this purpose; however, she could not decide about the direction of the ball. Now, she shifted to semiformal reasoning.

NP1: It is something like this: [when the string breaks] the ball frees itself into the emptiness. There is nothing to distract the ball now [either right or left]. If something is rotated fast and then released, it moves directly outside the circle [perpendicular to the circle].

R: Why did you make this choice?

NP1: Well, the string breaks and it goes outside. Because it escapes, this is the reason… All my experiences confirm this. Based on my experiences I am saying that if something is released while it is rotating it goes outside [perpendicular to the circle].

NP1 clearly refers to an alternative principle, a causal relationship (rotational motion and the direction of the object after release) to find a solution for the direction of the ball. As she stated, it is based on her experiences. These experiences are interpreted and verbalized in a way that “if something is released while it is rotating, it goes outside.”
What can we say about the character of this principle? The following quotations reveal its context dependence. Notice the confusion when she considers a lighter ball.

NP1: Just a minute, what about if it is a plastic ball [previously she considered a hammer]. Then what the ball does cannot be known…

A summary of the types of reasoning performed by NP1 is presented in Table 4.1.
<table>
<thead>
<tr>
<th>Problem</th>
<th>Reasoning</th>
<th>Principles</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Problem 1</td>
<td>Reasoning by mental simulation</td>
<td>N/A</td>
<td>Moves</td>
</tr>
<tr>
<td>Problem 2</td>
<td>Reasoning by mental simulation, Semiformal reasoning</td>
<td>Rotating objects would move perpendicular to the circle when they are released.</td>
<td></td>
</tr>
<tr>
<td>Problem 3</td>
<td>Reasoning by mental simulation</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Problem 4</td>
<td>Semiformal reasoning</td>
<td>The heavier an object, the stronger the pull (because of gravitation.) The stronger the pull, the faster the object gets.</td>
<td></td>
</tr>
<tr>
<td>Problem 5</td>
<td>Reasoning by mental simulation, Semiformal reasoning</td>
<td>Objects would move in a straight line if there is nothing acting on them.</td>
<td></td>
</tr>
<tr>
<td>Problem 6</td>
<td>Reasoning by mental simulation, Semiformal reasoning</td>
<td>N/A</td>
<td>Undecided</td>
</tr>
</tbody>
</table>

Table 4.1: Types of reasoning performed by NP1.
The Case of NP2

NP2 was a female Ph.D. student at the College of Education. She had majored in psychology in college. In high school, she took three physics courses, which covered the topics of mechanics, electricity, and optics. However, she was not interested in or took any other physics courses thereafter. She rated herself “poor” on the amount of her physics knowledge.

Reasoning. Throughout almost the whole problem-solving session, NP2 used semiformal reasoning to construct a model for each problem. She used reasoning by mental simulation only in one occasion while she was responding to the fourth problem (released bottles). Several examples are given below to illustrate her semiformal reasoning. The first example is extracted from her response to the second problem: she claimed that the ball would follow a curve line after the string breaks and the researcher asked why she thought so.

NP2: It has a velocity; actually I am not sure about the technical terms. The ball gains a velocity. While the ball is rotating, it gains a velocity. So, when we release it at some point, it will keep rotating a little more. After a considerable time passed over the cease of the applied force [causing the rotation], the ball would move according to the normal rules. [She explains what the normal rule is.] In other terms, what happens when you throw a ball? It goes in a straight line. So the ball would follow a straight line after a little curve. If we apply some force, the direction of the velocity would be in the direction of the force. When the force is not
available any more there is no reason for the ball to make a curve any more.

R: Are you saying that when the string breaks there is no reason for the ball to follow a curve line?

NP2: When the string breaks, previous things continue. Let’s say that the string breaks at this point. Normally it is expected to stop. In other words, it does not receive any force any more. However, previous force causes the ball to move a little more by following a curve line. When the effect of the previous force disappears, it continues its motion in a straight line.

R: Are you saying that if there is no force the ball follows a straight line?

NP2: No, it cannot move if there is no force. What I mean is that the previously applied force causes the ball to follow a curve line a little more because the nature of the force applied by the person was a circle.

R: Do you mean the ball stores the applied force somehow?

NP2: If you say so. I think it does but I could not claim that.

R: The ball knows its previous motion?

NP2: Well, there is something in the ball.

R: What is it? Are you saying that it is the force?

NP2: I am not sure if we can call it force. But there is something. I am not good at this [terminology] therefore I could not explain it clearly.

R: Let’s return to the straight line after a little curve? Is there anything on the ball while it is following a straight line?
NP2: Maybe velocity but there is no direction anymore. But immediately after
the string breaks, there is also direction [this is why it follows a curve line
a little more] because its [previous force] effect still continues. The person
has not rotated it just once, hasn’t he?

It is quite explicit that NP2’s reasoning in her statements is full of elements and
general principles due to her attempt to use a semiformal reasoning. Before entering into
the descriptions about the role of elements and principles in her semiformal reasoning, it
is better now to exemplify her reasoning by mental simulation. The quotations below
describe how she uses her mental simulation in her attempt to solve the fourth problem
(dropping bottles). Before she shifted into reasoning by mental simulation, she spent
quite a time to find a solution by semiformal reasoning. However, she could not decide
between two alternative principles. The first one is “the empty one would fall faster
because it is light and there is not much load to bring it down” and the second one is “the
full one would fall faster because it applies more pressure downward.” Although she did
not use the elements such as pressure appropriately, she had captured a good point
leading to the solution. However, she could not decide and finally used reasoning by
mental simulation.

R: What would be your best guess?

NP2: The heavier one. …I am imagining two things dropped from a building, a
piece of cotton and iron. The cotton is falling slowly by swinging in the
air. But the metal piece is falling as if it is pushing itself downward…

Elements and principles: What makes NP2’s reasoning semiformal rather than formal is
the basic question framing the descriptions of NP2’s use of elements and principles in her
attempt to construct a model for each problem. As NP2 stated several times with her own words, “I am not good at terminology,” NP2 had been suffering from the lack of explicit definitions for different kinds of elements. She frequently used different terms such as “force,” “energy,” and “pressure” as if they were interchangeable. Despite the ambiguity in elements, she had already managed to construct some general principles, which she transferred into the problem situations. Let’s see some examples of these principles: (a) “Objects move in a straight line if there is not any force acting on the object,” (b) “If we apply some force, the direction of the motion would be in the direction of the force,” and (c) “When the force acting on the object ceased, the ball keeps moving under the effect of this force a little more.” Although the principles stated in (a) and (b) are completely compatible with physics, principle (c) is not. In (a) and (b), NP2 refers to forces continuously acting on objects and people are quite familiar with the meaning of these forces such as pushing and pulling. However, in (c), NP2 attributes another characteristic to force, i.e., force as a mover. Objects store the previously applied force and continue their motion under the influence of this force for a while, which contradicts how physicists define this element. Consequently, her interpretation about the force element, which is incompatible with physics, leads her to an incompatible principle. A summary of the types of reasoning performed by NP2 is presented in Table 4.2.
<table>
<thead>
<tr>
<th>Problem</th>
<th>Reasoning</th>
<th>Principles</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-Semiformal reasoning</td>
<td>Objects would move in the direction of the pull.</td>
<td>Moves → Pull</td>
</tr>
<tr>
<td>2</td>
<td>-Semiformal reasoning</td>
<td>Objects are inclined to follow their previous motions.</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>-Semiformal reasoning</td>
<td>Objects can move only under the influence of force. A stronger force can eliminate the weaker one.</td>
<td>Strong kick → Weak kicks, Kick</td>
</tr>
<tr>
<td>4</td>
<td>-Reasoning by mental simulation</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>-Semiformal reasoning</td>
<td>Objects are inclined to follow their previous motions.</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>-Semiformal Reasoning</td>
<td>Vertical force has an affect on horizontal speed.</td>
<td>Late → Early</td>
</tr>
</tbody>
</table>

Table 4.2: Types of reasoning performed by NP2.
The Case of NP3

NP3 was a male Ph.D. student attending the College of Education. He earned his BA degree in English Language and Literacy. He took three physics courses in high school. These courses covered mechanics, electricity, and optics. He rated himself “poor” on the amount of his physics knowledge.

Reasoning. NP3 performed different types of reasoning in different occasions. Although the reasoning by mental simulation was dominant throughout the whole session, he also used semiformal and formal reasoning. He used formal reasoning during only one occasion, while he was working on the third problem (hockey puck). Sometimes, he shifted from one way of reasoning to another in the same problem.

In the following paragraphs, several types of reasoning used by NP3 are exemplified. The first example describes his reasoning by the mental simulation. NP3 was working on the second problem to find the path of the ball when the string breaks. First, he drew a straight-line tangent to the circle. Then he changed the drawing to a curve as if the ball was following its previous rotation.

R: Why did you first draw a straight line then the curve?

NP3: Why did I think it is a straight line? I think because of movies [pause]. When you throw a stone with a sling it moves in a straight line. Why curve? I am not sure. First it seemed to move in a straight line. Then, I thought about its shape and energy as if it is situated into a circular orbit. Thus, I thought it might follow a curve. However, I still think that it moves in a straight line [tangent to the circle]. Physically, I have no idea, but logically [it moves in a straight line].
R: What do you mean by saying logically?

NP3: I am imagining, I imagined a sling. A story about a Jewish boy came into my mind. He killed a giant with a sling. He throws [a rock] and it goes straightly to the giant’s head. Normally it goes straight.

Although NP3 attempted to put the problem situation into a conceptual framework by referring to the ball’s circular orbit and energy, he was not able to do that and immediately shifted to reasoning by mental simulation. The following quotations demonstrate NP3’s semiformal reasoning. He was working on the fourth problem. He was almost sure that both bottles reach the ground at the same time because he remembered the answer from a TV program. However, he got confused when he began to explain why.

NP3: I think I remember this problem from a physics class; the answer was different from what was expected. Oh yeah! I remember this from feather and iron experiment showed on TV, but was it in an airless environment? Probably, they reached the ground at the same time. The result was strange this is why it was shown on TV. If I say it was independent of weight, was it too contradictory to physics.

R: Just say whatever you are thinking.

NP: Logically, iron should drop faster [than the feather]. For instance when a truck is driven downhill, the heavier it is, the faster it gets, doesn’t it? Why does it get faster when it is loaded?

R: Did you see it? Does it get faster?
NP3: I don’t know. Logically, it does. There are lots of truck accidents [because of heavy load] but not that much car accidents. Actually, it is a different topic. How can I say [inaudible]? I completely think so, the heavier one drops faster [than the lighter one]…

NP3 could not decide between his “logical” explanation and the result of an experiment shown on TV. He oscillated for a while. Finally, he decided on the experimental result. However, he could not construct a consistent explanation for this result. What he calls a logical explanation refers to his interpretations of his own observations. It was definitely seen that he had formulated his observations/experiences in a way that led him to some principles. In the following paragraphs, NP3’s formal reasoning is exemplified.

Although it has been more than 10 years since NP3 took the physics courses, he still keeps some systematic knowledge structure, which can be applied to a broad range of situations. The following quotations are taken from NP3’s attempt to solve the third problem (hockey puck).

NP3: I remember this from physics classrooms. When the two things were collided [pause]. Was it momentum? [Asks himself]. It receives a kick: a simultaneous kick. It is something like the resultant of forces. Now, it is coming in this way. When it receives a kick it is pushed — of course it also depends on the effect of the kick. Because its previous energy continuous, I think it moves in the direction of the resultant of these two.

R: How did you think while you were working on this problem?
NP3: I am working by drawing, as I said, resultants like the resultant of forces, which I remember from high school. I also imagined billiard balls [he also used imaginary reasoning; however, his reasoning with vectors was dominant].

Elements and principles. NP3 was quite aware of his different ways of reasoning for different occasions. He made a distinction between “logical” and “physical” thinking. When he claimed logical explanations he was referring to his observations and experiences, which were either interpreted or uninterpreted. Reasoning with uninterpreted experiences had already been named as reasoning by mental simulation, which did not include either specific elements or principles – just the scenes appearing in his mind. However, when NP3 shifted to interpreted experiences, some elements and principles gain control over his predictions. While he was working on the fourth problem, it was quite obvious that he had already formulated a principle based on his observations about the motion of trucks driven downhill – “The heavier it is, the faster it gets.” His interpretation (the heavier it is, the faster it gets) is one step ahead of his mental simulation (the scene of the moving truck) in his reasoning. When the researcher prompted him by asking whether he really observed that heavier trucks get faster, his response reveals that he was not sure exactly what he had observed. However, the principle he formulated was easily transferred to the problem situation and began to shape his decision about the relative velocity of the bottles. A summary of the types of reasoning performed by NP3 is presented in Table 4.3.
<table>
<thead>
<tr>
<th>Reasoning</th>
<th>Principles</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Problem 1 - Semiformal</td>
<td>When a circular object receives an off center force it rotates. Rotating</td>
<td>Moves</td>
</tr>
<tr>
<td>reasoning</td>
<td>objects move in the direction of rotation.</td>
<td>Pull</td>
</tr>
<tr>
<td>Problem 2 - Reasoning by</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>mental simulation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Problem 3 - Reasoning by</td>
<td>Operations with vectors</td>
<td></td>
</tr>
<tr>
<td>mental simulation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Formal reasoning</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Problem 4 - Semiformal</td>
<td>The heavier an object, the faster it gets.</td>
<td></td>
</tr>
<tr>
<td>reasoning</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Problem 5 - Semiformal</td>
<td>Objects would move in a straight line if there is nothing acting on them.</td>
<td></td>
</tr>
<tr>
<td>reasoning</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Problem 6 - Semiformal</td>
<td>The longer the distance, the longer the time to travel.</td>
<td>Early</td>
</tr>
<tr>
<td>Reasoning</td>
<td></td>
<td>Late</td>
</tr>
</tbody>
</table>

Table 4.3: Types of reasoning performed by NP3.
The Case of NP4

NP4 is a male Ph.D. student at the College of Education. He earned his BA degree in the field of history. The only physics courses he took were in high school. These courses covered mechanics, electrics and optics. He rated himself “poor” on the amount of his physics knowledge.

Reasoning. NP4 used two types of reasoning, reasoning by mental simulation and semiformal reasoning throughout the session. Sometimes, he used both types of reasoning simultaneously especially, when the mental simulation does not provide an exact match with the problem situation. The following quotations are NP4’s attempts to solve the second problem (swinging ball). First, he tried to visualize the problem. However he could not find an exact scene. Then, he shifted to a semiformal reasoning by thinking about the “power” relations although “power” is not a legitimate element in this context from a physicist’s perspective.

NP4: Well [pause] what kind of ball is this?
R: You may think whatever you like.
NP4: I am thinking of a hammer. I think that if the hammer is thrown consciously [the string did not break], it would go somewhere around here tangent to the circle] although I could not imagine how far does it go. However, if the string is broken then it goes around here [perpendicular to the circle on the right hand side of the person]. Whether it is hammer or ball is important, I could not imagine what happens if it is a ball. It may go strangely. If it were something solid such as hammer or shell, it would go around here [perpendicular to the circle]…
R: What is in your mind while you were thinking about those?

NP3: I thought about the athletes throwing hammers or shells.

In the following quotations, it was noticed that NP4 shifted to a semiformal reasoning because his imaginary scene did not provide any clue what happens when the string breaks instead of thrown “consciously.”

NP4: Because something is changing here. If the person throws it, the power or whatever it is that the person was giving to the ball by swinging, would lead it to a determined point. However, when it is released [the string breaks] then the balance of the power would change and lead it to a strange point. I can comfortably say that if it were “thrown” in this position it would go to this point [tangent to the circle].

R: What would be the path of the ball?

NP4: [draws a curve opposite to the swinging direction]

R: Why does it follow a curve something like this?

NP4: I thought that this person applied some “power” in this direction so I concluded that it would move in this direction. However, I assumed that, if the string gets broken, this “balance” would be destroyed and it would move in a direction something like this [draws a curve toward the outside of the circle] because it seems impossible for it to move in this direction [straight ahead of the person] anymore and this unbalanced power would drive it outside the circle…

Elements and principles. Throughout the problem-solving session, it was quite obvious that there was no consistency in the use of elements in his explanations whenever
NP4 attempted to use semiformal reasoning. For example “power,” “force,” and even “velocity” were used as if they were interchangeable. Although NP4 was aware of the ambiguity in his use of elements, he did not consider this an important factor in his reasoning. For instance, the following quotation reveals NP4’s over flexibility in the use of elements, e.g., the use of “power”. “If the person throws it [deliberately], the power or whatever it is that the person was giving to the ball by swinging, would lead it to a determined point.”

The principles that NP4 had already constructed were based on vague terms, for example, his explanations for “balanced” and “unbalanced” motions. According to NP4, although deliberate (or conscious) actions on objects cause “balanced” motions, accidental actions cause “unbalanced” motions. Although it was difficult for him to explain the “unbalanced” motions, he was quite sure about his predictions corresponding to “balanced” motions (such as consciously throwing a ball) because many of his experiences or observations corresponded to balanced motions. He relied on one core principle in his explanations for “balanced” motions: “objects move in the direction of the applied power.”

While NP4 was working on the third problem (hockey puck), he used more specific principles. For example in the following statements, he was thinking about the direction of the hockey puck after the kick. Implicitly, he assumed that there must be something to make the object move by asking how the ball is coming.

NP4: Well. How is the ball coming? Has somebody kicked before?

R: Yes, let’s say that.
NP4: Well. Theoretically, to change its original direction this kick [the kick given in the problem] must be more powerful than the initial kick [the kick causing the ball to move in the given direction].

A summary of the types of reasoning performed by NP4 is presented in Table 4.4.
<table>
<thead>
<tr>
<th>Problem</th>
<th>Reasoning</th>
<th>Principles</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Problem 1</td>
<td>-Semiformal reasoning</td>
<td>When a circular object receives an off center force it rotates. Rotating objects would move in the direction of rotation.</td>
<td>Moves Pull</td>
</tr>
<tr>
<td>Problem 2</td>
<td>-Semiformal reasoning -Reasoning by mental simulation</td>
<td>Unintentional forces causes unbalanced motions.</td>
<td></td>
</tr>
<tr>
<td>Problem 3</td>
<td>-Reasoning by mental simulation  -Semiformal reasoning</td>
<td>Moving objects possess force. Bigger force eliminates the smaller ones.</td>
<td>Strong kick Weak kick Kick</td>
</tr>
<tr>
<td>Problem 4</td>
<td>-Semiformal reasoning</td>
<td>Heavier an object, the stronger the pull (because of gravitation.) Stronger the pull, faster the object gets.</td>
<td></td>
</tr>
<tr>
<td>Problem 5</td>
<td>-Semiformal reasoning</td>
<td>Objects would move in a straight line if there is nothing acting on them.</td>
<td></td>
</tr>
<tr>
<td>Problem 6</td>
<td>-Semiformal Reasoning</td>
<td>The longer the distance, the longer the time to travel.</td>
<td>Early Late Day 1 Day 2</td>
</tr>
</tbody>
</table>

Table 4.4: Types of reasoning performed by NP4.
NP5 was a male MA student in the College of Education. He earned his BA degree in Counseling and Guidance. The only physics courses he took were in high school. He took three physics courses, which covered mechanics, electricity, and optics. He did not take any other physics related courses thereafter and he rated himself “poor” on his knowledge of physics.

Reasoning. NP5 actively used two types of reasoning throughout the session, reasoning by mental simulation and semiformal reasoning. The following quotations are provided as examples of NP5’s reasoning by mental simulation. His response was for the fifth problem (semicircle). His immediate response occurred in a few seconds.

NP5: If we rotate the ball in this way it would move like this [he joins the two ends of the semicircle by drawing a curve.]

R: Does it enter the semicircle again?

NP5: Let me visualize it again.

R: When you drew a curve did you visualize it too?

NP5: Actually, I thought that it would repeat its previous motion after it exits the semicircle. When I was a child I had a little car and small plastic rails. By assembling these rails I could create different kinds of roads for the car. Once, I assembled a road like this [draws a road which looks like a semicircle] and sent the car on it. When the car exits the road it moved like this [draws a straight line tangent to the circle]. Was it the same shape [asks himself silently]?

R: What are you thinking right now?
NP5: I am imagining how would it go — I am visualizing it in my mind [pause].

Yes, it moves like this [a straight line tangent to the semicircle].

In the following statements, NP5 was working on the second problem (swinging ball). He claimed that the path of the ball would be a curve (the ball is inclined to follow its circular motion after the string breaks). His reasoning was loaded with explicit or implicit elements and principles. Saving the interpretations about the nature of these conceptions for the next section NP5’s semiformal reasoning is provided below.

R: Why do you think so [the ball makes a curve]?

NP5: There are two things, which should be taken into the consideration [in this problem]. The first one is how fast the person is swinging the ball and the second one is the two forces acting on the ball. The first force provides the ball to move outside [of the circle] because the string was holding the ball. The other force causing the ball to swing around the circle makes the ball diverted [in the way of the swing]…

R: Did you think about these two forces immediately after you read the problem?

NP5: There is, actually, only one force, which causes the ball to swing in a determined circle. But, the string keeps it into the circle. When the ball released, it moves outside. Yes there is only one force but it looks like two. As if one was pushing it forward and the other one was pushing it outside.

Elements and principles. When NP5 shifted from reasoning by mental simulation to semiformal reasoning, one of the basic elements he frequently used was “force.” NP5
replaced many of the terms stated in the problem such as “pull,” “kick,” or “swing” with the element of “force” while he was thinking about the problems. However, several characteristics that NP5 attributed to the element of force are not compatible with physics. For example “force as a mover,” NP5 implicitly states that that moving objects possess force. It was obvious that NP5 could not distinguish between different elements such as “force,” “energy,” and “momentum” and he referred to all of them as “force.” The following quotation demonstrates his use of “force” in place of “energy.”

**R:** Are you saying that there is a force while the puck is sliding on the ice?

**NP5:** Yes, I think it is under the influence of a force otherwise it could not slide.

Why should it slide then? In other words, there must be a force for the puck to move.

Several principles used by NP5 throughout the problem-solving session were as follows: (a) “Rotating objects are inclined to move outside when they are released,” (b) “Bigger force can eliminate the smaller one,” (c) “Lighter objects are more inclined to stay in the air than the heavier one (if they have the same size).” A summary of the types of reasoning performed by NP5 is presented in Table 4.5.
<table>
<thead>
<tr>
<th>Problem 1</th>
<th>-Reasoning by mental simulation</th>
<th>N/A</th>
<th>Moves</th>
</tr>
</thead>
</table>

| Problem 2 | -Semi-formal reasoning  
-Moving objects possess force. |
| Problem 3 | -Reasoning by mental simulation  
-Bigger force eliminates the smaller one. |
| Problem 4 | -Semi-formal reasoning  
The heavier an object, the stronger the pull. (because of gravitation.)  
Stronger the pull, faster the object gets. |
| Problem 5 | -Reasoning by mental simulation  
N/A |
| Problem 6 | -Semi-formal Reasoning  
The longer the distance, the longer the time to travel. |

Table 4.5: Types of reasoning performed by NP5.
Conclusion

The analysis of the data collected from the non-physics group has provided enough evidence to conclude that the way the participants reason is an important factor to describe the nature of alternative conceptions. Two ways of reasoning, reasoning by mental simulation and semiformal reasoning, were dominant throughout the problem-solving sessions. It is also noticed that the function of elements and principles is framed by the way the participants reason.

Reasoning by mental simulation can be defined as the most primitive reasoning because there is almost no interpretation attributed to the corresponding observations or experiences. In other words, these observations or experiences held by the participants have not been refined nor solidified into any kind of conceptual structure. However, they already have a status to be transferred into problem situations. Figure 4.2 demonstrates the process of reasoning by mental simulation. When the participant reads the problem statement, it activates a specific scene or scenes in the mind of the participant, which is identical or similar to the scene described in the problem statement, and this specific scene in the mind of the individual is directly transferred to construct a model.

Because of the uninterpreted nature of the experiences and observations, reasoning by mental simulation does not include any kind of explicit principle and the use of elements is just for the purpose of communication – for the purpose of translating the mental scenes into verbal statements. In other words, they are communicatory tools rather than cognitive.
A little more articulated reasoning performed by the participants in the non-physics group is defined as semiformal reasoning. In this case, the reasoning is framed by interpreted experiences or observations. This interpretation can be defined as perceiving the regularities — repeatedly observed or experienced patterns are expected to happen in a similar way. In other terms, there is an inference based on experiences or observations, which leads to alternative principles such as “objects drop when they are released” or “objects do not move if there is no force acting on them.” In the case of semiformal reasoning, participants refer to these formulated principles rather than specific instances of observation or experience.

The process of semiformal reasoning is demonstrated with solid lines in figure 4.3. Dotted lines correspond to the formation of principles. The core object of the semiformal reasoning is alternative principles. Different from the reasoning by mental simulation, specific observations or experiences are peripheral in this case. Participants’ reference to these instances is just to validate the principle in hand — they are not the object of the reasoning anymore.
Figure 4.3: Semiformal reasoning.

The role of elements is inherent in semiformal reasoning because the structure of principles includes the interrelationships (mostly causal) among different elements. However, because the construction process of these principles is not based on a conscious and systematic inquiry, the meanings of elements are not explicit. Their use is mostly conventional and situated in common language of the society to which the individual belongs. Therefore, several elements such as force, power, and energy are used as if they were interchangeable.
Individual Cases of the Physics Group

This section includes the analysis of data collected from the physics group. There were five participants in this group who are referred to as P1, P2, P3, P4, and P5. The same procedure followed for the cases of the non-physics group is performed in this section.

The Case of P1

P1 was a male Ph.D. student in the College of Education. He had majored in physics education in college. He also earned an MS degree in the same field.

Reasoning. As it was expected, formal reasoning was dominant throughout the whole problem-solving session with P1 because of his strong academic background in physics. However, his reference to reasoning by mental simulation and semiformal reasoning was also noticed on several occasions. In the following quotations, P1’s formal reasoning is exemplified while he was working on the second problem (swinging ball).

P1: If the string beaks at this point, it would move like this [draws a straight line tangent to the circle]… Whether we consider the air friction or not does not matter, it would move in this direction. Wherever the string breaks, the ball would move in the direction of its velocity at that point. There is no other way that the ball would move because of the inertia. There is only one thing, gravitation, that might cause confusion. However, we could not observe the effect of gravitation [because we are observing from the top]. Therefore, it would move like this [tangent to the circle].

R: Why did you draw a straight line?
P1: Because of the inertia. When the force acting on an object is removed at some point, the object would continue its motion in the same direction and velocity held by the object at that point. Consequently, after this point [the string breaks], it would move like this [draws a straight line].

R: Can you explain why it is like that [straight line]?

R: Because the velocity of the ball is always tangent to the circle at every point of the circle.

In this situation, it was explicitly seen that P1’s reasoning is not contaminated with either reasoning by mental simulation or semiformal reasoning. His prediction was based solely on scientific principles, particularly the principle of inertia -- “When the force acting on an object is removed at some point, the object would continue its motion in the same direction and velocity hold by the object at that point.” However, this is not always the case for P1. In the following statements, P1’s use of semiformal reasoning is illustrated while he was working on the fourth problem (dropping bottles).

P1: Last year, we taught this topic. We neglect the rotations of the bottles, right?

R: Do you think they rotate while they are falling?

P1: Sure, they rotate as far as there is friction [because of air].

R: Would they keep rotating?

P1: Of course they rotate all the way down.

R: Why do you think they rotate?

P1: Well, there is a friction. Apart from friction… [pause]. Actually, I do not know why, I thought about rotational inertia immediately.
R: What kind of rotation are you thinking about?

P1: There might be different kinds of rotations such as spinning…

In this case, P1 is referring to an alternative principle, “Falling objects rotate all the way down.” He did not provide any physical explanation for this principle. In fact, there is no such physical principle describing the rotation of the objects when they are released. However, this principle did not directly affect his prediction. In the following statements, he shifted to formal reasoning again.

P1: Because I know the purpose of the problem, I can give you an explanation for that. They, both, would reach the ground at the same time. It is independent of the weight of the bottles. We can demonstrate that mathematically. Its potential energy [before released] and its kinetic [when hits the ground] would be equal. In other terms, mgh [potential energy] equals 1/2mvsquare [kinetic energy]. Mass cancels out in this equation; consequently the speeds would be equal for both bottles.

In this case, he used a formal reasoning by citing a scientific principle, “conservation of energy,” by considering a frictionless environment. In the following statements, he shifted to semiformal reasoning again when the researcher prompted him to consider a frictional environment.

R: What about in an environment with air?

P1: They would drop at the same time again. Because they have the same surface, the frictional force affects both of them in the same way. Consequently it does not matter whether there is friction or not.
After a few minutes, P1 realized that in a frictional environment, the bottles would not reach the ground at the same time. However, as the quotation above demonstrates, his immediate response is based on an alternative principle, “the same force acted on objects, the same speed they would gain.” In fact, this principle contradicts physics because the speed gained by objects not only depends on the force acting on them but also the mass of the objects.

In the following quotation, another type of reasoning, reasoning by mental simulation, performed by P1 is presented. Notice how conscious P1 was in the use of this type of reasoning. In that moment, he was working on the first problem (yo-yo).

P1: I am thinking about rotational inertia but I am weak on this topic. Well, I am trying to remember the concepts related to the rotational inertia because I think the yo-yo would rotate [pause].

R: What is the first thing came into your mind?

P1: Nothing, no answer pop up in my mind yet…I have no idea how can we solve [this problem] with rotational inertia so I cannot say which way would it go. I have two things in my mind. First, I am thinking with physics and second, I am thinking with my intuition [the exact translation of the term he used is “instinct;” however, “intuition” is more appropriate in this context]. Intuitively speaking, when we pull, it would move in the direction of the pull; considering that there is a friction between the yo-yo and the table. But, in physics problems, the friction is usually described…[he keeps thinking about the friction and rotational inertia]

R: What would be your best guess?
In these kinds of situations, I could not decide because I usually get wrong when I solve a problem by visualizing it in my mind.

What you mean by saying, “visualizing?”

I am trying to find an answer by imagining that I am pulling a yo-yo resting on a carpet or a table. But, I know that it leads me to a wrong answer whenever I do this. I am aware that I should use physics concepts to solve the problem.

Elements and principles. The role of elements and principles became visible whenever P1 performed either semiformal or formal reasoning. Throughout the whole problem-solving session, P1 was very consistent in the meaning of the elements he used. The meanings of the elements used by P1 were always compatible with physics.

The principles used by P1 were usually scientific. Only on one occasion did P1 refer to alternative principles, which were noticed while he was working on the fourth problem (dropping bottles). These principles were formulated as follows: “falling objects rotate all the way down” and “the same force acted on objects, the same speed they would gain.” A summary of the types of reasoning performed by P1 is presented in Table 4.6.
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<th>Principles</th>
<th>Model</th>
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<td>-Reasoning by mental simulation</td>
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<tr>
<td>Problem 2</td>
<td>-Formal reasoning</td>
<td>Scientific Principles</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>-The direction of the velocity of rotating objects is always tangent to the circle.</td>
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<td></td>
<td></td>
<td>-An object would continue its motion in the direction of its previous velocity if there is no force acting on it.</td>
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<tr>
<td>Problem 3</td>
<td>-Formal reasoning</td>
<td>Scientific Principles</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>-Operations with vectors</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>-Principle of inertia</td>
<td></td>
</tr>
<tr>
<td>Problem 4</td>
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<td>Scientific Principles</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-Semiformal reasoning</td>
<td>-Dropping objects would speed up with a constant acceleration independent of their weights.</td>
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<tr>
<td></td>
<td></td>
<td>Alternative Principles</td>
<td></td>
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<td></td>
<td></td>
<td>-The same force causes the same acceleration</td>
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<tr>
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<td></td>
<td>-Falling objects rotate all the way down</td>
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<tr>
<td>Problem 5</td>
<td>-Formal reasoning</td>
<td>Scientific Principles</td>
<td></td>
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<tr>
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<td></td>
<td>-The direction of the velocity of moving objects is tangent to the circle.</td>
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<td>-An object would continue its motion in the direction of its previous velocity if there is no force acting on it.</td>
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<tr>
<td>Problem 6</td>
<td>-Formal Reasoning</td>
<td>Scientific Principles</td>
<td>Same time</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-Operations with vectors</td>
<td></td>
</tr>
</tbody>
</table>

Table 4.6: Types of reasoning performed by P1.
**The Case of P2**

P2 was a male MA student at the College of Education. He had majored in Physics Education in college.

*Reasoning.* P2 consistently used formal reasoning almost throughout the whole problem-solving session. His reference to reasoning by mental simulation and semiformal reasoning was noticed only on one occasion. The following quotations demonstrate how he used a formal reasoning while he was working on the second problem (swinging ball)

P2: If the string breaks at this point, the direction of the ball at this breaking point would be like this [draws a straight line tangent to the circle] with a constant speed. This speed combined with gravitational acceleration causes a projectile motion.

R: Consider you are observing from the top.

P2: Then it would move just like this [draws a straight line tangent to the circle].

R: Why did you draw a straight line?

P2: I thought about the direction of the velocity at the breaking point. The direction of the velocity would be tangent to the circle.

R: Did you think any other possibility?

P2: Physics taught us that the direction of the velocity of an object making a rotational motion is always tangent to the circle. When the string breaks, the object would move in this direction because there is no force [distracting the object].
P2’s statements in response to Problem 2 show that his reasoning is framed by solely scientific principles. These principles are as follows: “the direction of the velocity of an object making a rotational motion is always tangent to the circle” and “the object would move in its original direction, if there is no force acting on it.” For this problem, P2 did not refer to either reasoning by mental simulation or semiformal reasoning.

However, the following quotations demonstrate how P2 shifted to semiformal reasoning while he was working on the fourth problem (dropping bottles). First, he employed formal reasoning and concluded that both bottles would reach the ground at the same time by considering a frictionless environment. His reasoning was based on scientific principles, “released objects accelerate with a constant acceleration which is defined as gravitational acceleration. Consequently, objects speed up in the same rate independent of their weights.” Notice how he shifted to semiformal reasoning when the researcher asked him to consider a frictional environment.

R: What about the air friction, does it make any difference?

P2: If they are both in the same environment, I do not think that it makes any difference.

R: Why do you think so?

P2: Both of them seem to reach the ground at the same time. Friction affects both of them in the same way [because they have the same surface conducting with air].

He used an alternative principle in this case, “the same force acted on objects, the same acceleration objects gain.” However, in terms of scientific conceptualization, acceleration not only depends on the force acting on an object but also the mass of the object
(Newton’s second low: $a=F/m$). Although the same frictional force acts on the bottles, due to the different masses of each bottle, each bottle would gain different acceleration. Therefore, objects would not reach the ground at the same time in a frictional environment. It would be naïve to assume that P2 does not know this core physical principle. One logical explanation of his behavior might be that the alternative principle acted faster than the scientific one at this given moment.

Another type of reasoning performed by P2 was reasoning by mental simulation. However, reasoning by mental simulation did not have an active role in his prediction. The following quotation demonstrates the way P2 performed this type of reasoning. Notice how conscious he was in the use of this type of reasoning. He explicitly makes a distinction between his formal reasoning (physical thinking with his words) and reasoning by mental simulation (logical thinking with his words). The statements below extracted from the session while he was working on the fourth problem (dropping bottles). The researcher prompted him by asking, “do you feel like that?”

R:  Well, do you feel like that [they drop at the same time]?

P2:  When I think logically, I visualize the falling of a fruit and a leaf rather than two bottles and they do not reach the ground at the same time. Observations in the nature confirm that they do not reach the ground at the same time. Therefore, we are experiencing difficulty to accept the physical result. The heavier one seems to drop immediately.

Elements and principles. The meanings for the elements held by P2 were always consistent with physics while he was using either semiformal or formal reasoning. He employed formal reasoning by explicitly referring to the scientific principles almost
throughout the whole problem-solving session. Only on one occasion, while he was working on the fourth problem, did P2 refer to an alternative principle: “the same force acted on objects, the same acceleration objects gain.” A summary of the types of reasoning performed by P2 is presented in Table 4.7.
Problem 1
-Formal reasoning
Scientific Principles
- An object would move in the direction of the net force acting on it.

Problem 2
-Formal reasoning
Scientific Principles
- The direction of the velocity of rotating objects is always tangent to the circle.
- The object would continue its motion in the direction of its previous velocity if there is no force acting on it.

Problem 3
-Formal reasoning
Scientific Principles
- Operations with vectors

Problem 4
-Formal reasoning
Scientific Principles
- Dropping objects would speed up with a constant acceleration independent of their weights.
Alternative Principles
- The same force causes the same acceleration.

Problem 5
-Formal reasoning
Scientific Principles
- The direction of the velocity of rotating objects is tangent to the circle.
- The object would continue its motion in the direction of its previous velocity if there is no force acting on it.

Problem 6
-Formal reasoning
Scientific Principles
- Operations with vectors

Table 4.7: Types of reasoning performed by P2.
The Case of P3

P3 was a male Ph.D. student in the College of Education. He had majored in physics in college.

Reasoning. Formal reasoning was dominant throughout the whole problem-solving session with P3. However, he was also quite comfortable with using reasoning by mental simulation and semiformal reasoning whenever he could not put a problem statement into a formal conceptual framework. The following quotations exemplify how he employed formal reasoning by using two scientific principles: “When an object is rotating, the direction of the force is toward the center and the velocity is tangent to the circle” and “The object would continue its motion in the direction of its previous velocity if there is no force acting on it.” At this moment, he was working on the second problem (swinging ball).

P3: The first thing came into my mind are the laws of rotational motion. The direction of the force is toward the center and the velocity is tangent to the circle. If the string breaks and we observe it from the top, the object would follow a straight-line tangent to the circle.

R: Can you explain why would it follow a straight line?

P3: Because we are observing from the top, I am thinking in two dimensions. In two dimensions the path of the ball would be linear. The object would continue its motion in the direction of whatever the direction it has at the very point at which the string breaks [tangent to the circle].

In the following paragraphs, P3’s semiformal reasoning is exemplified. He was currently working on the first problem (yo-yo). As he stated in his own words, “I can’t
He could not put the problem statement into a formal conceptual framework. He immediately assumed that “the yo-yo would rotate due to the off-center force applied by pulling the string and it would move in the direction of rotation.” Consequently, he concluded that the yo-yo would move in the opposite direction of the pull – in the direction of the rotation such in the case of a wheel.

P3: I can’t think of any formula or motion laws right now. I am thinking about my experiences with yo-yo… [He thinks about the problem and asks several questions about the friction and the weight of the yo-yo.]

P3: Should I give only one answer?
R: Any way you want.

P3: I would say it moves in this direction [draws a line opposite to the pull]
R: Why did you think so?

P3: It looks like a frictional force. I thought about a wheel. If the direction of the friction were in this way then the wheel would move in the same direction. Similarly, think about the yo-yo. It would move in the opposite direction of the pull such in the case of the wheel; parallel with friction, which is opposite to the pull.

After these explanations, the researcher asked his immediate response about the problem. The statements below describe the kind of reasoning he performed immediately after he read the problem.

R: What was the first thing came into your mind when you read the problem?

P3: The first thing I thought is simple; I visualized it in my mind.

R: What appeared in your mind?
P3: I am pulling the string and the yo-yo moves backward as if it was thrown backward. Well, how can I say [pause]? Because of the flexibility of the string the yo-yo seems to move backward.

As it is clearly seen from the P3’s statements, his immediate response is framed by reasoning by mental simulation. Although his immediate response (framed by reasoning by mental simulation) and final decision (framed by semiformal reasoning) are the same, he disregarded reasoning by mental simulation and brought an explanation framed by semiformal reasoning.

The following quotations provide another example of the way P3 performs reasoning by mental simulation. Notice how conscious P3 is about his reasoning and how he blocked the outcome generated by reasoning by mental simulation.

P3: I do not know why but whenever I think about these kinds of problems, I feel as if I was taking an exam. Immediately after I read the question, I thought that the heavier one drops faster.

R: How did you think immediately after you read the problem?

P3: While I was reading the problem I thought visually — I imagined it in my mind and the full one was dropping faster.

R: What makes you think that the heavier one drops faster?

P3: This is more like a life problem than a physics problem and I want to think about my daily life experiences. Stone or bottles are directly related to the daily life experiences and by relying on my daily life observations I am thinking that the heavier one drops faster.

R: Are you saying that you do not want to use physics?
P3: No, it is not that I do not want to use physics. I just couldn’t think immediately that I should use physics because my experience with this topic is not directly related to physics instead it is related to my daily life experiences. My daily life experiences acts faster than physics. However, there is a mechanism in my mind and it says, “Stop it, stop it, this is wrong.”

Elements and principles. P3 was consistent in the meanings of elements throughout the whole problem-solving session and they were always compatible with physics. Except for one occasion (yo-yo problem), he constantly used scientific principles. The alternative principle he used in that occasion was formulated as follows: “objects would rotate when they receive an off center force and rotating objects would move in the direction of the rotation.” A summary of the types of reasoning performed by P3 is presented in Table 4.8.
<table>
<thead>
<tr>
<th>Problem</th>
<th>Reasoning</th>
<th>Principles</th>
<th>Model</th>
</tr>
</thead>
</table>
| Problem 1 | -Semiformal reasoning -Reasoning by mental simulation | **Scientific Principles**  
-When a circular object receives an off center force it rotates.  
-Rotating objects would move in the direction of rotation. | ![Diagram](image1.png) |
| Problem 2 | -Formal reasoning | **Scientific Principles**  
-The direction of the velocity of rotating objects is always tangent to the circle  
- An object would continue its motion in the direction of its previous velocity if there is no force acting on it. | ![Diagram](image2.png) |
| Problem 3 | -Formal reasoning | **Scientific Principles**  
-Operations with vectors | ![Diagram](image3.png) |
| Problem 4 | -Formal reasoning -Reasoning by mental simulation | **Scientific Principles**  
-Dropping objects would speed up with a constant acceleration independent of their weights. | ![Diagram](image4.png) |
| Problem 5 | -Formal reasoning | **Scientific Principles**  
-The direction of the velocity of moving objects is tangent to the circle.  
- An object would continue its motion in the direction of its previous velocity if there is no force acting on it | ![Diagram](image5.png) |
| Problem 6 | -Formal reasoning | **Scientific Principles**  
-Operations with vectors | ![Diagram](image6.png) |

Table 4.8 Types of reasoning performed by P3.
The Case of P4

P4 was a male Ph.D. student in the College of Education. He had majored in physics in college.

Reasoning. Formal reasoning was dominant throughout the whole problem-solving session with P4. However, his formal reasoning could not always generate the expected scientific models. This is because the meaning of the force element held by P4 was not consistent with physics. His reference to reasoning by mental simulation and semiformal reasoning was also noticed on several occasions. In the following statements, the way P4 performed formal reasoning is illustrated while he was working on the second problem (swinging ball).

P4: I think after the string breaks, the ball would move tangent to the circle in a straight line. When the string breaks, the force pulling the ball inside is not available anymore. Consequently, it would move tangent to the circle after the string breaks.

R: Why do you think it is tangent to the circle?

P4: I am looking at the situation in terms of the net force [acting on the ball]. Before the string breaks, there is a force toward the center because of the string. When the string breaks, this force is nullified; consequently, there is no force in this direction any more. The only force available is tangent to the circle.

R: Does the object move under the influence of this force?

P4: Yes, it slows down gradually.
It was quite explicit that P4 is using a formal reasoning which is not contaminated by either reasoning by mental simulation or semiformal reasoning and his prediction is completely compatible with physics. However, there is a serious problem in his reasoning in terms of the meaning of the force element. The meaning of the force element attributed by P4 is not compatible with physics. He states that there is tangential force acting on the ball. His statement is based on an assumption that moving objects have force in the direction of motion although it is not a necessity in terms of physical conceptualization. The following quotations demonstrate more explicitly how this issue about the meaning of the force element leads him to alternative models. At this moment, he was working on the third problem (hockey puck).

P4: If it was coming with a constant speed, the force in the direction of the X is zero. The only force is the kick applied in the direction of the Y. Consequently, the ball would move in the direction of the Y--in the direction of the kick.

R: Isn’t there any deviation?

P4: No. As far as there is no other force there is no deviation. When you kick the ball, you are applying a force and the ball gets accelerated. It moves in the direction of the kick and follows a straight line. The ball would move in the direction of the net force. In this situation, if the ball is coming at a constant speed then there is no force in this direction and the net force is in the direction of the Y. Consequently it moves in this direction.
He used two basic principles of Newtonian mechanics, “an object would move in the direction of the net force acting on it” and “if an object moves in a constant speed, then the net force acting on it is zero.” However, the meaning of force held by P4 contradicts physics. He believes that there is still force after the kick although the kick is an instantaneous force and acts only a few seconds at most. Similar to the participants in the non-physics group, P4 interprets force element as something transferable to the objects. Consequently, although he was using scientific principles he came up with an alternative model.

In the following statements, the way P4 performs semiformal reasoning is exemplified while he was working on the fourth problem (dropping bottles).

P4: Both bottles would reach the ground at the same time. Because both bottles have the same geometrical shape, the frictional force acting on the bottles would be the same and the travel time is independent of the weight of the bottles. It only depends on the gravitational acceleration and the height. Because both bottles were dropped from the same height and the gravitational acceleration is constant, both bottles would reach the ground at the same time.

Similar to the cases of P1 and P2, P4 used the same alternative principle, “the same force causes the same acceleration,” while he was handling the friction caused by the air. However, the weights of the bottles are different, therefore the same force (air friction) acting on the balls would, in fact, cause different accelerations for each bottle.
In the following quotations, P4’s reference to reasoning by mental simulation is operating. He was still working on the same problem and the researcher asked him “do you feel like that [the bottles drop at the same time]?”

P4: There is always a temptation that the heavier one drops faster. Although I am giving you this explanation [physical explanation that they drop at the same time] something inside me provokes as if the heavier one drops immediately and the lighter one drops slowly by swinging in the air such in the case of a piece of iron and a feather.

**Elements and principles.** P4 was consistent with the meanings of the elements throughout the whole problem-solving session. However, the meaning of the force element was not compatible with physics. This problem caused him to generate alternative models, which was not compatible with physics. He conceptualized the force element as if it was something transferable to objects.

He also constantly used scientific principles in most of the cases; however, because of the problem in the meaning of the force element the choices of the appropriate principles for the corresponding problems were not always successful. His reference to alternative principles was noticed only during one occasion. The alternative principle used in this occasion was formulated as “the same force causes the same acceleration.” A summary of the types of reasoning performed by P4 is presented in Table 4.9.
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<tr>
<td>-Semi formal reasoning</td>
<td>-When a circular object receives an off center force it rotates.</td>
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<td></td>
<td>-Rotating objects would move in the direction of rotation</td>
<td></td>
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<tr>
<td>Problem 2</td>
<td><strong>Scientific Principles</strong></td>
<td></td>
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<tr>
<td>-Formal reasoning (with a</td>
<td>-An object would move in the direction of the net force acting on it.</td>
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<tr>
<td>problem with force element)</td>
<td></td>
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<tr>
<td>Problem 3</td>
<td><strong>Scientific Principles</strong></td>
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<tr>
<td>-Formal reasoning (with a</td>
<td>-An object would move in the direction of the net force acting on it.</td>
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<td>problem with force element)</td>
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<tr>
<td>Problem 4</td>
<td><strong>Scientific Principles</strong></td>
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</tr>
<tr>
<td>-Formal reasoning</td>
<td>-Dropping objects would speed up with a constant acceleration independent</td>
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<td></td>
<td>of their weights.</td>
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<tr>
<td>-Semi formal reasoning</td>
<td><strong>Alternative Principles</strong></td>
<td></td>
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<tr>
<td>-Reasoning by mental</td>
<td>-The same force causes the same acceleration.</td>
<td></td>
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<tr>
<td>simulation</td>
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<tr>
<td>Problem 5</td>
<td><strong>Scientific Principles</strong></td>
<td></td>
</tr>
<tr>
<td>-Formal reasoning (with a</td>
<td>-Objects would move in the direction of the net force acting on them.</td>
<td></td>
</tr>
<tr>
<td>problem with force element)</td>
<td></td>
<td></td>
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<tr>
<td>Problem 6</td>
<td><strong>Scientific Principles</strong></td>
<td></td>
</tr>
<tr>
<td>-Formal reasoning</td>
<td>-Operations with vectors</td>
<td></td>
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<tr>
<td></td>
<td>Same time</td>
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</table>

Table 4.9: Types of reasoning performed by P4.
The Case of P5

P5 was a male Ph.D. student in the College of Education. He had majored in physics education in college.

Reasoning. Formal reasoning was dominant throughout the whole problem-solving session with P5. However, similar to the case of P4, the meaning of the force element held by P5 was not consistent with physics. Therefore, his reference to scientific principles did not always lead him do the scientific models. Reasoning by mental simulation and semiformal reasoning were also noticed on several occasions. In the following statements, the way P5 uses formal reasoning is demonstrated. At this moment, he was working on the third problem (hockey puck).

P5: Well, net force is zero [while the ball is coming in this direction with a constant speed]. Net force is zero and it is moving in a constant speed. Now we applied an upright force at this point. Are we kicking at the center of the puck?

R: Yes.

P5: I am thinking now. Well, there is only one force, which is at this upright direction. Then it would move in this direction.

R: What if the puck is coming so fast?

P5: It would be in the same direction again. I am thinking whether it would make a curve or wouldn’t. But there is only one force, which is in this direction [upright]. Therefore, it does not matter how fast the puck is coming [it would move in the direction of the net force].
Although P5’s used a formal reasoning by using several scientific principles, he failed to generate a scientific model. He used two basic principles of Newtonian mechanics, “an object would move in the direction of the net force acting on it” and “if an object moves in a constant speed, then the net force acting on it is zero.” However, the meaning of force held by P5 was not consistent with physics. Consequently, in spite of the scientific principles he used, he could not generate a scientific model. He assumed that there is still force acting on the puck after the kick; however, the kick is an instantaneous force and acts only a few seconds at most. Therefore, there is no force at all after the kick. His interpretation about the force element was based on an immediate assumption that force is something that might be transferable to objects.

In the following quotation P5’s semiformal reasoning is illustrated. Notice how semiformal reasoning is intertwined with formal reasoning.

P5: I am thinking about what would happen in this plane [horizontal plane]…

If the ball is under the influence of a net force, it goes like this [draws a straight line between perpendicular and tangential axis of the circle].

R: Why did you draw a line like this?

P5: Because there is a centrifugal force perpendicular to the circle. There is also another force because of the rotational motion tangent to the circle [pause].

R: What is happening when the string breaks?

P5: When the string breaks, the ball still wants to go in this direction [tangent to the circle]. In the mean time, centrifugal force enters into the equation.

R: What you mean by saying that “the ball still wants to go in this direction?”
P5: It is inclined to repeat its previous motion; however, it could not be able to do that…

R: Can you tell me how many forces there are when the string breaks?

P5: There is no force toward the center anymore. It still wants to follow a rotational motion. On the other hand, there is a centrifugal force. We removed this force [toward the center] and we are left with this one [tangent to the circle] and the centrifugal force. Consequently, the ball would move under the influence of the resultant of these two forces in a straight line.

R: Can you tell me more about the force tangent to the circle?

P5: If this ball is rotating like this, this force [tangent] is due to the person rotating the ball. The ball could not leave the circle because the tension on the string and the centrifugal force are equal. But, when the string breaks, there are only two forces, centrifugal force and the force tangent to the circle. Consequently, the ball would move in a straight line as a resultant of these two forces. In fact, it seems to make a curve but thinking with physics there are only two forces.

R: You feel that the ball would make a curve but you ignore that?

P5: Well, it might make a little curve…

Immediately after P5 read the problem statement, he began to think with scientific principles although he continued to use the same physically incompatible meaning of the force element. However, he switched to semiformal reasoning by referring to alternative principles such as “It is inclined to repeat its previous motion” and “It still wants to
follow a rotational motion.” These principles were not separated from the scientific ones by P5; instead, they were used as if they were scientific principles and shaped his prediction.

The following quotations provide another example of semiformal reasoning performed by P5 by relying on an alternative principle, “the longer the distance, the longer the time to travel.” In this case, he was working on the sixth problem (boat in the river).

P5: I think we need to know some values [such as the velocity of the boat and the stream] to answer the question.

R: What would be your best guess without them?

P5: I guess second day would take longer. For example, consider a strong stream — it would drag the boat to quite a distant point. In this case, the boat should travel longer. Consequently, it took longer time for the boat to take this longer distance.

In the following statements, how the reasoning by mental simulation performed by P5 is exemplified. In this case, P5 was working on the fourth problem (dropping bottles). After he gave physical explanations, the researcher prompted him by asking, “Do you feel like that?”

P5: Well, when I imagined it in my mind, it does not seem to be like that [both bottles reach the ground at the same time]. But, in terms of physics, you know that both bottles reach the ground at the same time. However, you still could not stop thinking if it happens in the real life.
Elements and principles. P5 was consistent with the meaning of the elements throughout the whole problem-solving session. However, similar to the case of P4, the meaning of the force element used by P5 was not consistent with physics. This problem caused him to generate alternative models, which were not compatible with physics. He conceptualized the force element as if it was something transferable to objects.

In most of the cases, he used scientific principles; however, because of the problem in the meaning of the force element the choices of the appropriate principles for the corresponding problems were not always accurate. His reference to alternative principles was noticed on two occasions (Problems 2 and 6). The alternative principles used on these occasions were formulated as follows: “Objects are inclined to repeat their previous motion” and “the longer the distance, the longer the time to travel.” A summary of the types of reasoning performed by P5 is presented in Table 4.10.
<table>
<thead>
<tr>
<th>Problem</th>
<th>Reasoning</th>
<th>Principles</th>
<th>Model</th>
</tr>
</thead>
</table>
| Problem 1 | -Formal reasoning  
-Reasoning by mental simulation | **Scientific Principles**  
-An object would move in the direction of the net force acting on it. | ![Pull](image) |
| Problem 2 | -Formal reasoning (with a problem with force element)  
-Semiformal reasoning | **Scientific Principles**  
-An object would move in the direction of the net force acting on it.  
**Alternative principle**  
-Objects are inclined to repeat their previous motion. | ![Kick](image) |
| Problem 3 | -Formal reasoning (with a problem with force element) | **Scientific Principles**  
-An object would move in the direction of the net force acting on it. | ![Kick](image) |
| Problem 4 | -Formal reasoning  
-Reasoning by mental simulation | **Scientific Principles**  
-Dropping objects would speed up with a constant acceleration independent of their weights.  
**F=ma** | ![F=ma](image) |
| Problem 5 | -Formal reasoning (with a problem with force element) | **Scientific Principles**  
-Objects would move in the direction of the net force acting on them. | ![F=ma](image) |
| Problem 6 | -Semiformal Reasoning | **Alternative Principles**  
-The longer the distance, the longer the time to travel. | ![Early Late](image) |

Table 4.10: Types of reasoning performed by P5.
Research Questions (RQ)

In this section, the data collected from the physics group were analyzed purposefully to address the research questions of this study in light of the reference frame generated by the data collected from the non-physics group. Three main questions were initially generated as follows: (1) Do individuals keep their alternative conceptions after they have acquired scientific conceptions? (2) Assuming that individuals who acquired scientific conceptions also have alternative conceptions, how are these different conceptions nested in their conceptual structure? (3) What kind of knowledge, skills, and reasoning are necessary to transfer scientific principles instead of alternative ones in the construction of a valid model?

Based on the reference frame generated for the nature of alternative conceptions the research questions were reformulated in this section whenever it is necessary. Because the nature of alternative conceptions was framed by the way the participants reason, special attention was given to the participants’ reasoning in problem-solving sessions. In response to the first research question, specific instances of the participants’ reasoning by mental simulation and semiformal reasoning were sought to provide evidence about the coexistence of multiple conceptions. However, the nature of the second question required a higher level of interpretation due to the lack of a direct link between verbal reports and mental structure. Nevertheless, participants’ reasoning and the use of elements, principles, or mental images on different occasions made it possible to generate logical arguments. In response to the third question, the focus of analysis was to find patterns across the cases that influence the participants’ choices of reasoning and the selection of elements and principles.
RQ-1: Do individuals keep their alternative conceptions after they have acquired scientific conceptions?

Taking the reference frame as a base, the more fruitful question to be asked at this point is whether the participants in the physics group refer to reasoning by mental simulation or semiformal reasoning because the notion of “alternative conception” seems to be framed by these two types of reasoning as evident in the analysis of the data collected from the non-physics group.

In the subsequent paragraphs several examples of reasoning by mental simulation are provided. First, P1’s reasoning by mental simulation is quoted below while he was working on the first problem (yo-yo).

P1: I am thinking about rotational inertia but I am weak on this topic. Well, I am trying to remember the concepts related to the rotational inertia because I think the yo-yo would rotate [pause].

R: What is the first thing came into your mind?

P1: Nothing, no answer popped up in my mind yet… I have no idea how can we solve [this problem] with rotational inertia so I cannot say which way would it go. I have two things in my mind. First, I am thinking with physics and second, I am thinking with my intuition [the exact translation of the term he used is “instinct,” however, “intuition” is more appropriate in this context]. Intuitively speaking, when we pull, it would move in the direction of the pull; considering that there is a friction between the yo-yo and the table. But, in physics problems, the friction is usually described. [He keeps thinking about the friction and rotational inertia]
R: What would be your best guess?

P1: In these kinds of situations, I could not decide because I usually get wrong when I solve a problem by visualizing it in my mind.

R: What you mean by saying, “visualizing?”

P1: I am trying to find an answer by imagining that I am pulling a yo-yo resting on a carpet or a table. But, I know that it leads me to a wrong answer whenever I do this. I am aware that I should use physics concepts to solve the problem.

The last statement of P1, “I am aware that I should use physics concepts to solve the problem,” has a special importance that will be addressed in response to the third research question. In the following quotations, P2’s reasoning by mental simulation is provided. He is working on the fourth problem (dropping bottles).

P2: They would drop at the same time. Why do I think so? Because of physics, it is in my life all over [he begins to give a physical explanation of why they drop at the same time.]

R: Well, do you feel like that [they drop at the same time]?

P2: When I think logically, I visualize the falling of a fruit and a leaf rather than two bottles and they do not reach the ground at the same time.

Observations in the nature confirm that they do not reach the ground at the same time. Therefore, we are experiencing difficulty to accept the physical result. The heavier one seems to drop immediately. [In the rest of this session, P2 explains how he handles this confusion, which will be addressed in the next questions].
Below, P4’s reasoning by mental simulation for the same problem is provided. After he provides a physical explanation, the researcher asked the same question, “Do you feel like that?”

P4: There is always a temptation that the heavier one drops faster. Although I am giving you this explanation [physical explanation that they drop at the same time] something inside me provokes as if the heavier one drops immediately and the lighter one drops slowly by swinging in the air such in the case of a piece of iron and a feather.

The examples provided confirm that the reasoning by mental simulation still exists among the participants of the physics group and the acquisition of scientific knowledge and procedures do not extinguish the scenes and images in their minds – they are still working actively in the background.

In the following paragraphs, a few examples concerning the use of semiformal reasoning are provided. In the following statements, P1 was working on the fourth problem. Interestingly, P1 had already formulated an alternative principle that “falling objects rotate.” He did not provide any physical explanation for this principle. In fact, there is not any physical principle requiring the rotation of the objects when they are released.

P1: Last year we taught this topic. We neglect the rotations of the bottles, right?

R: Do you think they rotate while they are falling?

P1: Sure, they rotate as far as there is friction [because of air].

R: Would they keep rotating?
P1: Of course they rotate all the way down.

R: Why do you think they rotate?

P1: Well, there is a friction. Apart from friction [pause]. Actually, I do not know why, I thought about rotational inertia immediately.

R: What kind of rotation are you thinking about?

P1: There might be different kinds of rotations such as spinning.

Another example of the semiformal reasoning is provided below. In this case, P3 was working on the first problem. He directly assumed that the yo-yo would rotate when the string was pulled. His assumption is probably based on an implicit principle that “when the objects with circular shape receive an off-center force it rotates.”

P3: I can’t think of any formula or motion laws right now. I am thinking about my experiences with yo-yo [He thinks about the problem and asks several questions about the friction and the weight of the yo-yo.]

P3: Should I give only one answer?

R: Anyway you want.

P3: I would say it moves in this direction [draws a line opposite to the pull]

R: Why did you think so?

P3: It looks like a frictional force. I thought about a wheel. If the direction of the friction were in this way then the wheel would move in the same direction. Similarly, think about the yo-yo. It would move in the opposite direction of the pull such in the case of the wheel; parallel with friction, which is opposite to the pull.
In the following quotations P5’s semiformal reasoning is provided as a final example. He is working on the sixth problem (river). He worked on the problem for a few minutes to figure out what would be the resultant velocity of the boat. The rest of the session is quoted below. He relied on an alternative principle in his prediction, “the longer the distance, the longer the time to travel.”

P5: I think we need to know some values [such as the velocity of the boat and the stream] to answer the question.

R: What would be your best guess without them?

P5: I guess second day would take longer. For example, consider a strong stream — it would drag the boat to quite a distant point. In this case, the boat should travel longer. Consequently, it took longer time for the boat to take this longer distance.

RQ-2: Assuming that individuals who acquired scientific conceptions also have alternative conceptions, how are these different conceptions nested in their conceptual structure?

To address this question unambiguously it is better to begin with the way of reasoning and narrow it down to its components. In response to the previous research question, by providing several examples, it has already been established that reasoning by mental simulation and semiformal reasoning do not necessarily extinguish with the acquisition of scientific conceptions. Therefore, the components of these two types of reasoning seem to still exist in the participants’ mental structure. Because the components of the reasoning by mental simulation and semiformal reasoning differ, it is
better to discuss the position of each reasoning separately. Let’s begin with the position of the reasoning by mental simulation and then proceed to the semiformal reasoning.

*The position of the reasoning by mental simulation.* The objects of reasoning by mental simulation are the mental images or scenes reproduced by the participants spontaneously in response to the problems. However, the objects of formal reasoning are well-defined elements and principles. There is a clear-cut difference between the two types of reasoning. As it is expected, the participants were always aware of which reasoning they were performing in a given moment. The statements provided in response to the first research question regarding the participants’ reasoning by mental simulation demonstrates how conscious they were in the use of reasoning by mental simulation. For example P1 makes a clear distinction between the two types of reasoning by saying, “I have two things in my mind. First, I am thinking with physics and second, I am thinking with my intuition…. I am trying to find an answer by imagining that I am pulling a yo-yo resting on a carpet or a table.”

Here is another example from the problem-solving session with P4. “There is always a temptation that the heavier one drops faster. Although I am giving you this explanation [physical explanation that they drop at the same time] something inside me provokes as if the heavier one drops immediately and the lighter one drops slowly by swinging in the air such in the case of a piece of iron and a feather.”

It is quite obvious that the participants compartmentalized these two ways of reasoning and they consider the reasoning by mental simulation not reliable in terms of its predictions. They simply disregard the outcome of the reasoning by mental simulation, although they could not stop its performance. Maybe another example makes this
statement more explicit. In the following quotations, P3 was working on the fourth problem (dropping bottles).

P3: I do not know why but whenever I think about these kinds of problems, I feel as if I was taking an exam. Immediately after I read the question, I thought that the heavier one drops faster.

R: What makes you think that the heavier one drops faster?

P3: This is more like a life problem than a physics problem and I want to think about my daily life experiences. Stone or bottles are directly related to the daily life experiences and by relying on my daily life observations I am thinking that the heavier one drops faster.

R: Are you saying that you do not want to use physics?

P3: No, it is not that I do not want to use physics. I just couldn’t think immediately that I should use physics because my experience with this topic is not directly related to physics instead it is related to my daily life experiences. My daily life experiences act faster than physics. However, there is a mechanism in my mind and it says, “Stop it, stop it, this is wrong.”

The position of the semiformal reasoning. There is a close similarity between semiformal and formal reasoning in terms of their functional mechanism — both of them operate with elements and principles. However, the structure of these elements and principles differ significantly between two types of reasoning. A brief summary of these differences is presented in Table 4.11.
Table 4.11: Components of formal and semiformal reasoning.

<table>
<thead>
<tr>
<th>Elements</th>
<th>Principles</th>
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</thead>
<tbody>
<tr>
<td><strong>Semiformal</strong></td>
<td><strong>-Generated by perceived regularities in nature</strong></td>
</tr>
<tr>
<td>- Vague</td>
<td>- Not tested systematically</td>
</tr>
<tr>
<td>- Conventional — situated in common language</td>
<td>- No consensus about the validity</td>
</tr>
<tr>
<td>- Not operationalized</td>
<td>- Context dependent</td>
</tr>
<tr>
<td><strong>Formal</strong></td>
<td><strong>-Formed by scientific inquiry</strong></td>
</tr>
<tr>
<td>- Well defined</td>
<td>- Tested systematically</td>
</tr>
<tr>
<td>- Purposefully generated</td>
<td>- Consensus about its validity</td>
</tr>
<tr>
<td>- Mostly operationalized</td>
<td>- Context independent general statements</td>
</tr>
</tbody>
</table>

The similarity between the mechanisms of semiformal and formal reasoning seems to be more influential than the difference between its components; therefore, it impeded the participants’ ability to make a distinction between these two types of reasoning. Although the participants compartmentalized the reasoning by mental simulation and formal reasoning explicitly, semiformal and formal reasoning were intertwined in a way that the components of semiformal reasoning easily leaked into the components of formal reasoning. Therefore, participants were unaware that they were actually performing semiformal reasoning even if they thought that they were performing formal reasoning. For example, in response to the fourth problem, P1 unconsciously transferred an alternative principle, “falling objects rotates all the way down,” into the problem situation as if it was a scientific principle. Similarly, while P5 was working on the sixth problem he relied on an alternative principle, “the longer the distance, the longer it takes to travel.”
RQ-3: What kind of knowledge, skills, and reasoning are necessary to transfer scientific principles instead of alternative ones in the construction of a valid model?

While addressing the first two questions, it was well established that neither reasoning nor its components framing the nature of alternative conceptions disappear after the acquisition of scientific knowledge. However, it was also explicitly noticed that the more the participants were aware of their cognitive processes and knowledge structure the more they were capable of transferring scientific conceptions in the construction of a model. In the context of this question, although it seems needless to emphasize the importance of content knowledge, several problematic issues were noticed about the use of elements and should be addressed. As well as content knowledge and awareness, the role of the context in which a problem is situated and the context in which a participant’s knowledge base is situated cannot be ignored in the construction of a model. In the following subsections, these factors are described.

Content knowledge. The acquisition of a strong knowledge base in a domain cannot be ignored in a problem-solving situation. In the context of this study, two fundamentals of the knowledge base are identified: “elements” and “principles.” Although individuals could easily get acquainted with some basic physical principles such as “force causes acceleration” or “an object would move in the direction of the net force acting on it,” the acquisition of the meaning of each basic element constructing a principle seems rather neglected which causes some serious issues in problem-solving situations. Two examples are provided below to demonstrate how physical principles can mislead the participants if the participants have not acquired an appropriate meaning for the corresponding elements.
In the following statements, P5 was working on the third problem (hockey puck). He used two basic principles of Newtonian mechanics, “an object would move in the direction of the net force acting on it” and “if an object moves at a constant speed, then the net force acting on it is zero.” However, the meaning of force held by P5 is not consistent with the definition in physics. He believes that there is still force after the kick although the kick is an instantaneous force and acts only a few seconds at most. Similar to the participants in the non-physics group, P5 interprets force element as something transferable to the objects. Consequently, although he was using scientific principles he came up with an alternative model.

P5: Well, net force is zero [while the puck is coming in this direction with a constant speed]. Net force is zero and it is moving in a constant speed. Now we applied an upright force at this point. Are we kicking at the center of the ball?

R: Yes.

P5: I am thinking now. Well, there is only one force, which is at this upright direction. Then it would move in this direction.

R: What if the ball is coming so fast?

P5: It would be in the same direction again. I am thinking whether it would make a curve or wouldn’t. But there is only one force, which is in this direction [upright]. Therefore, it does not matter how fast the ball is coming [it would move in the direction of the net force].

The second example is quoted from the session with P4. He was working on the same problem and his response pattern is quite similar to that P5.
P4: If it was coming with a constant speed, the force in the direction of the X is zero. The only force is the kick applied in the direction of the Y. Consequently, the ball would move in the direction of the Y, in the direction of the kick.

R: Isn’t there any deviation?

P4: No. As far as there is no other force there is no deviation. When you kick the ball, you are applying a force and the ball gets accelerated. It moves in the direction of the kick and follows a straight line. The ball would move in the direction of the net force. In this situation, if the ball is coming in a constant speed then there is no force in this direction and the net force is in the direction of the Y. Consequently it moves in this direction.

Awareness. In response to the second research question, how the participants’ awareness of their own reasoning helped them to compartmentalize the reasoning by mental simulation and formal reasoning was exemplified. This ability seems to make them able to control the outcomes of the reasoning by mental simulation and hinder the overgeneralization of specific observations or experiences. However, it is also noticed that semiformal reasoning is not as much distinguished as the reasoning by mental simulation. Several examples provided in response to the second question verify that “alternative principles” can easily take their place among the “scientific principles.” Therefore, the participants could easily transfer alternative principles in the process of constructing a model. For example, P1 was unaware that he was transferring an alternative principle, “objects rotate while they were falling,” while he was working on
the Problem 4. Similarly, P5 did not hesitate to use an alternative principle, “the shorter the distance, the shorter the time to travel,” while he was working on the Problem 6.

Process of science. It was well established in the previous section that an individual’s awareness of her/his different types of reasoning and knowledge base is a necessity for use of scientific conceptions. However, it can be logically deduced that the knowledge about the process of science is a primary condition to make a distinction between different types of conceptions and make a choice in favor of scientific ones. Although it was not explicitly stated by the participants, their deliberate actions to use scientific conceptions reveals that they have an epistemological structure leading them to scientific conceptions. Individuals’ acquaintance with process of science in terms of how science generates its knowledge claims from simple elements to complicated theories constitutes their epistemological structure. Participants verbal reports provided in several occasions, such as “I know that I need to use physics to solve the problem” or “There is a mechanism in my mind and it says that stop it stop it this is wrong,” confirm that this epistemological structure provides a judgmental mechanism about the validity and reliability of specific conceptions and making a choice in favor of scientific ones.

Context. In the previous sections, more attention was given to the personal factors such as the participants’ level of awareness and competency with regard to content knowledge. However, it was also explicitly noticed that the structure of the problem constitutes an external factor guiding the participants’ reasoning and the use of conceptions. The following quotations extracted form the session with P3 demonstrates how the context defined in the problem affects his reasoning.

R: What makes you think that the heavier one drops faster?
P3: This is more like a life problem than a physics problem and I want to think about my daily life experiences. Stone or bottles are directly related to the daily life experiences and by relying on my daily life observations I am thinking that the heavier one drops faster.

R: Are you saying that you do not want to use physics?

P3 No, it is not that I do not want to use physics. I just couldn’t think immediately that I should use physics because my experience with this topic is not directly related to physics instead it is related to my daily life experiences.

As P3 stated, the more the problem is situated in an everyday-related context, the more he is stimulated to reason with alternative conceptions. This inclination toward the alternative conceptions in an everyday-related context is not surprising at all because all the participants except for P1 responded that they would hardly use physics concepts in their everyday-related activities to the direct question of “Do you use physics concepts in your everyday related activities?” In the following statements, P2 clearly explains why he does not prefer to use scientific conceptions in everyday-related activities:

P2: In many of the problems, everything is well defined and you know what you are looking for in it. For example, they say the speed is constant or there is no friction. However, normal life is not like that; there are no standards in normal life. In contrary, it is flexible and you can manipulate almost everything.

This chapter began with the analyses of the data collected from the non-physics group. These analyses led the researcher to generate a reference frame for the nature of
alternative conceptions. In the subsequent sections, the focus of analyses was shifted to the data collected from the physics group. The purpose of these analyses was to present a context for the data collected from the physics group. Finally, the research questions were addressed based on the data collected from the physics group by referring to the reference frame. The next chapter is devoted to the conclusions of the study. This chapter includes a summary of the results, discussions, and implications.
The conceptual change model has been widely accepted and has influenced the instructional practices in the science education community for more than two decades. However, several aspects of this model have been challenged by researchers from different perspectives. This study is particularly motivated by the philosophical arguments challenging the core premise of the conceptual change model, “when students’ central concepts are inadequate to explain new phenomena successfully, students must replace their central concepts.” In simplest form, these arguments state that people construct different domains of knowledge and different modes of perception in different situations. According to this argument, holding different conceptualizations is inevitable and expecting a replacement in individuals’ conceptual structure is not plausible in terms of instructional practices. In addition to this argument, the failure of the instructional strategies inspired by the conceptual change model intrigued this researcher to inquire empirically whether or not the individuals who acquired scientific conceptions have replaced their alternative conceptions.

However, there were two serious issues to be handled before beginning this inquiry. The first one was the ambiguity in the meaning of the term “conception.” To overcome this ambiguity, a framework was developed and three facets of conceptions
were identified as “elements,” “principles,” and “models.” In simplest form, each facet was defined as follows. Elements are individual terms corresponding to the individual entities in the universe. In the domain of physics, these terms mostly correspond to the abstract entities such as energy, force, and acceleration. Principles refer to the propositions or relationships among different entities. Therefore, principles require some level of interpretation about natural or artificial events to capture the relationships. In short, principles are the product of individuals’ either conscious or unconscious abstractions from the regularities repeating themselves throughout a broad range of observations or experiences. Elements and principles constitute the fundamental components of an individual’s conceptual structure. In other words, if we define problem-solving as a process of finding an unknown by using what has already been known, elements and principles constitute what has already been known by an individual. In this respect, models refer to the explanatory mental structure generated in response to the unknown by transferring the appropriate elements and principles.

The second issue was about the nature of alternative conceptions. How individuals generate alternative models was the basic question to be explored. Problem-solving sessions conducted with five participants whose physics knowledge were minimal provided detailed insight into this question. In the analysis of these sessions, more attention was given to the process rather than the product of problem solving. In this way, a reference frame was generated for the nature of alternative conceptions.

The way the participants reason was the most striking pattern immediately noticed across the cases that framed how the participants constructed models. Two types of reasoning which were dominant across the cases were categorized as “reasoning by
mental simulation” and “semiformal reasoning.” The reasoning by mental simulation operated with mental scenes reproduced by the participants simultaneously by recalling their previous observations or experiences that had not been yet refined or solidified into any kind of conceptual structure. However, semiformal reasoning operated with interpreted observations or experiences. This interpretation was defined as the perception of regularities in nature — repeatedly observed or experienced patterns are expected to happen in a similar way. In other terms, there is an inference based on experiences or observations, which leads to principles such as “objects drop when they are released” or “elastic objects bounce when they hit a surface.” In the case of semiformal reasoning, participants used these formulated principles rather than specific instances of observation or experience. The role of elements was inherent in semiformal reasoning because the structure of principles included the interrelationships (mostly causal) among different elements. However, because the construction process of these principles was not based on a conscious and systematic inquiry, it was obvious that the meanings of elements were not explicit. Their use was mostly conventional and situated into the common language of the society to which the individual belongs. Therefore, several elements such as force, power, and energy were used as if they were interchangeable.

Reasoning by mental simulation and semiformal reasoning and their components provided a fruitful reference frame to address the main purpose of this study outlined by three research questions: (1) Do individuals keep their alternative conceptions after they have acquired scientific conceptions? (2) Assuming that individuals who acquired scientific conceptions also have alternative conceptions, how are these different conceptions nested in their conceptual structure? (3) What kind of knowledge, skills, and
reasoning are necessary to transfer scientific principles instead of alternative ones in the construction of a valid model?

In response to the first research question, specific instances regarding the use of reasoning by mental simulation and semiformal reasoning were sought throughout the problem-solving sessions with the physics group. The participants’ verbal reports revealed that mental images or scenes framing the reasoning by mental simulation had not disappeared after the acquisition of scientific conceptions. Several participants acknowledged that reasoning by mental simulation kept working in the background even while they were trying to use physics concepts to solve the problems. In regard to the semiformal reasoning, several examples were presented about the participants’ reference to alternative principles, which provided enough evidence to conclude that alternative principles had not necessarily disappeared after the acquisition of scientific principles.

In response to the second research question, the positions of the reasoning by mental simulation and semiformal reasoning were sought by focusing on the specific instances of the participants’ use of these two types of reasoning. It was clear that the participants compartmentalized the reasoning by mental simulation and formal reasoning. They were always aware of which reasoning they were performing at a given moment. They simply disregarded the products of the reasoning by mental simulation and relied on the formal reasoning in their predictions. However, in regard to the semiformal reasoning, compartmentalization was not as clear as the case demonstrated in the reasoning by mental simulation. The analysis of the specific situations in which the participants performed semiformal reasoning revealed that semiformal and formal
reasoning were intertwined in a way that the components of semiformal reasoning could easily take their place among the components of formal reasoning.

Figure 5.1 demonstrates the relative positions and functions of the three types of reasoning. Although the participants did not allow “reasoning by mental simulation” to interfere in their models, “semiformal reasoning” sneaked into models without the participants’ awareness. The principles of semiformal reasoning were used as if they were scientific principles. Therefore, although reasoning by mental simulation did not cause any problem in the process of model construction, semiformal reasoning stood as a serious issue in this process.

Figure 5.1: The positions of the types of reasoning.
The responses generated for the first and second research questions not only assured the basic assumption of the coexistence of multiple conceptions but also laid groundwork for the inquiry about the factors stimulating the participants’ use of scientific conceptions. The question mark in Figure 5.1 corresponds to these factors; more specifically it refers to the question of “what does block the performance of reasoning by mental simulation and reflect back to another type of reasoning?” In this sense, four factors noticed throughout the problem-solving sessions were categorized as follows: (a) participants’ level of competency in content knowledge, (b) participants’ level of awareness of the existence of different types of reasoning and conceptions, (c) participants’ level of knowledge about the process of science, and (d) the context in which the problems are situated.

Discussion and Implications for Instructional Practices

Many of the researchers specializing in the field of alternative conceptions and conceptual change have situated themselves in a constructivist paradigm either by explicitly stating their positions or implicitly referring to the core literature in constructivist paradigm. This is because the first premise of constructivism provides an excellent framework for inquiry in this domain. This premise shed light on individuals’ pre-instructional conceptions by stating that, “knowledge is not passively received from the environment, but it is actively constructed by cognizing subjects.” Therefore, it is natural to observe that students come to science classrooms with some pre-established ideas (alternative conceptions) that might contradict scientific conceptions. One solution to the issue of alternative conceptions has emerged as the Conceptual Change Model and
it has influenced much of the above-mentioned literature and instructional practice for more than two decades.

Although the issue of alternative conceptions has been situated under the constructivist paradigm, the way it has been handled so far does not satisfy the whole notion of constructivism and generates an internal conflict. This is because the notion of “adaptation” framed by the second premise of constructivism has been neglected. According to this premise, “knowledge acquisition is an adaptive process that organizes one’s experiential world.” Similar to organisms’ physiological adaptation to the environment, individuals need to cognitively fit into the environment in which they perform a broad range of activities from simply drinking a glass of water to ice-skating. The environment constraining all these activities is defined as the experiential world. The basic question that should be asked at this point is “Does scientific reasoning or conceptions provide individuals to cognitively fit into their experiential world?” This question can simply be answered by outlining the purpose of science. The purpose of science is to find universal principles, laws, and theories describing nature (Popper, 1983). However, the term “universal” extends the experiential world of science from the smallest atomic particles to the black holes billions of miles away from the earth. This nature of science reveals the radical difference between an average person’s experiential world and the experiential world of science.

Even if we put aside the more advanced theories of physics corresponding to micro particles or objects with very high speed (e.g., relativity, quantum or string theories) and restrict the discussion to a more elemental level of physics, Newtonian mechanics, the difference between the experiential world of science and that of average
people does not disappear because the purpose of creating general knowledge claims still exists behind the theory of Newtonian mechanics. The purpose of creating general knowledge claims forces scientists to create an “ideal” world to eliminate the context-dependent factors. This “ideal” world, even defined by an elemental theory, significantly differs from the experiential world of average people because of the exclusion of contextual factors (for example air friction). However, these contextual factors, especially air, constitute a significant part of an individual’s experiential world. The lack of a direct match between two experiential worlds and the complicated nature of scientific theories impede the application of Newtonian mechanics to an individual’s experiential world. Furthermore, the necessity of acting quickly in daily life situations does not allow scientific conceptions to be a candidate as a cognitive tool for individuals to fit into their experiential world.

However, individuals have already developed some cognitive tools to handle everyday-related situations. In this study, two types of reasoning, reasoning by mental simulation and semiformal reasoning, are noticed as the most common cognitive tools among the participants. Because of the simplicity and explicit compatibility with individuals’ experiential world, these tools enable individuals to cognitively adapt to their experiential world. In this sense, any instructional practice aiming to extinguish these cognitive tools is against the notion of “adaptation.”

This argument can be elaborated with a simple example. Let’s consider two principles. The first one is an alternative principle, which can be easily generated based on daily life experiences. -- “An object in motion cannot go far if there is no force acting on it,” and the second one is a scientific principle, namely Newton’s first law. -- “An
object in motion tends to stay in motion with the same speed and in the same direction.” Apparently, scientific principle is situated into an “ideal” environment by excluding friction. Therefore, application of this principle to the experiential world of an individual requires several other steps to handle the effects of friction. Consequently, it gets complicated and slows down the cognitive process. However, in spite of its ambiguity and context dependency, the alternative principle refers directly to everyday-related situations without the necessity of handling extraneous factors. Considering the everyday-related activities such as moving furniture at home, passing the salt at the table, or just simply performing a game (say basketball), the basic requirement is acting quickly and unfortunately, scientific principles cannot satisfy this requirement. In this sense, any attempt to extinguish alternative principles means asking individuals to give up their basic cognitive tools regulating their everyday activities.

These arguments do not mean, in any way, that scientific conceptions do not work in our experiential world; instead, it is a perfect tool to solve almost every imaginable problem that can be encountered in everyday-related situations. The point is that using scientific conceptions requires not only a high level of competency but also a considerable amount of time. However, everyday-related activities do not allow individuals to devote that much time for simple unproblematic actions.

The results of this study confirm that even the individuals who have gained competency in physics have not replaced the above-mentioned adaptive tools such as reasoning by mental simulation and semiformal reasoning. Therefore, instructional strategies aimed to create conceptual change in terms of replacement of alternative conceptions with scientific conceptions are not plausible. The results of this study suggest
that the process of expected change in individual’s conceptual structure should be a “regulation” of conceptions rather than a “replacement”. The process of regulation can simply be defined as the compartmentalization of different types of reasoning. This process makes it easier for individuals to allocate the appropriate resources for the corresponding situations, especially the activation of formal reasoning in a problem-solving situation.

Figure 5.2: Conceptual regulation

Figure 5.2 demonstrates the most extreme case of an initial stage in which all types of reasoning are intertwined. In the physics group, only semiformal and formal reasoning were intertwined. However, it is quite possible to observe the interference of all types of reasoning among the individuals who have just begun to learn physics. It is also possible to observe additional types of reasoning such as a type of reasoning framed by religious beliefs. Especially in biological science, this possibility cannot be ignored for the topic of evolution.

Although the design of this study with a small number of participants does not allow constructing a grounded theory about the coexistence of alternative and scientific conceptions, the following implications for instructional practices can be generated.
• More attention should be given to help students be aware of the existence of different ways of reasoning and conceptualizations rather than stimulating a conceptual change in terms of replacement of alternative conceptions with scientific ones.

• Discussions about the process of science should be embedded into instructional practices. How science generates its knowledge claims and what makes scientific knowledge unique should be a part of these discussions.

• The differences between the experiential world of science and the experiential world of average individuals should be explicitly defined.

• Students should be stimulated to make reflections on their own knowledge structures and cognitive processes.

• Many of the elements of science such as force, power, and energy are also actively used in common language. However, the meanings of these elements are vague in common language and they can easily be substituted for each other. Therefore, the scientific meaning of these elements should be explicitly provided rather than just assuming that they are already known.

**Implications for Future Research**

The literature in the area of alternative conceptions and conceptual change has been suffering from the lack of a manageable form for the notion of “conception” because of the use of a single term, “conception,” for a multifaceted notion. To minimize this conceptual confusion, three forms of “conceptions” were proposed in this study:
elements, principles, and models. Although these forms provided a fruitful framework for the analysis and interpretations of the data in this particular study, the fruitfulness of this framework should be tested throughout a broad range of studies.

As well as alternative conceptions held by the students, the types of reasoning they are performing should be a part of the investigations to better understand the students’ pre-instructional ideas. In this study, two types of reasoning were observed and categorized as reasoning by mental simulation and semiformal reasoning. However, these categories were extracted from the data collected from a very small number of participants. Therefore, deeper studies should be conducted with a larger number of participants. It is also necessary to extend this inquiry to different age groups to understand the ways of reasoning used by each age group.

This study provided enough evidence to claim that the coexistence of alternative and scientific conceptions is unavoidable and it was concluded that expecting a replacement in students’ conceptual framework is not plausible for instructional practices. This study proposed a tentative model of “conceptual regulation” for learning science. However, this model could not be enriched because of the limitations of the available data and the restricted time frame. It is necessary to extend the scope of the data and analysis to develop a more articulate model.
APPENDIX A

RECRUITMENT LETTER
Dear (participant’s name),

My name is Omer F. Ozdemir. I am a graduate student majoring in science education at The Ohio State University. I am interested in investigating individuals’ knowledge structure and cognitive processes. I am asking for your consent to participate in this study, which will help me understand the structure of your conceptual knowledge and its function in problem-solving situations.

The purpose of this study is to (a) find evidences about the coexistence of different conceptions, (b) understand the structure of coexistence in an individual’s conceptual framework, and (c) understand the process of constructing a model in response to encountered problems. In order to do this, I am going to ask you to work through a series of problems, and to “think aloud” as you are working on each problem. What is meant by think aloud is that you should say everything you are thinking from the time you first see the problem until you reach a solution. It is important for this study to obtain every detail of what you are thinking while working on the problem. After you reach a solution, I will ask you several questions regarding your solution. Your responses will be recorded on a tape. It will take approximately two hours for each participant. Hours are flexible depending upon your schedule.

Your participation in this study is voluntary, and you are free to withdraw from participation at any time during the study. All information will be kept strictly confidential by assigning an anomalous name that will substitute for your name on all materials. No actual names will be used in any report of the research. The videotapes will be used for research purposes only and they will be kept in a secure place.

If you have any questions related to this study, please feel free to contact me at (614) 431-6155. If you have any questions concerning your rights as a participant in this study, you may contact the Office of Research Risks Protection, The Ohio State University at (614) 292-5958.

Sincerely,
Omer Ozdemir
APPENDIX B

ACADEMIC BACKGROUND
Academic Background

1. From which high school did you graduate? ...........................................

2. In which branch did you major in high school? .......................................

(a) Mathematics    (b) Science    (c) Literature    (d) Other: ..............

3. How many courses did you take in the following domains in high school?
   (Please check the appropriate boxes.)

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<th>2-3</th>
<th>More than 3</th>
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</thead>
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<td></td>
<td></td>
</tr>
<tr>
<td>Literature</td>
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<tr>
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<td>Biology</td>
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</table>

4. From which university did you graduate? .......................................  

5. From which department did you graduate? .....................................  

6. How many courses did you take in the following domains in university?
   (Please check the appropriate boxes.)

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<thead>
<tr>
<th></th>
<th>None</th>
<th>1</th>
<th>2-3</th>
<th>More than 3</th>
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<tbody>
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<tr>
<td>Physics</td>
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<tr>
<td>Chemistry</td>
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<td>Biology</td>
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</table>
7. How would you rate yourself on the amount of knowledge that you know for the following domains? (Please check the appropriate boxes.)

<table>
<thead>
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<th></th>
<th>Poor</th>
<th>Fair</th>
<th>Good</th>
<th>Very Good</th>
</tr>
</thead>
<tbody>
<tr>
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<td></td>
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<td>Biology</td>
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APPENDIX C

PROBLEMS
Problems

1. A yo-yo resting on a table is pulled as illustrated in the diagram below, but not so strongly as to cause it to slide on the table. Which way does the yo-yo move? (diSessa, 1983)

![Diagram of a yo-yo being pulled](image)

2. A heavy ball is attached to a string and swung in a circular path in a horizontal plane as illustrated in the diagram below. At the point indicated in the diagram, the string suddenly breaks at the ball. If these events were observed from directly above, what would be the path of the ball after the string breaks. (Hestenes, Wells, & Swackhamer, 1992)

![Diagram of a ball swinging in a circle](image)

3. While a hockey puck is moving in the given direction below, it receives a kick. What would be the path of the hockey puck after the kick?

![Diagram of a hockey puck moving with a kick](image)
4. Two identical plastic bottles are dropped from the top of a building at the same instant of time, but one is full and the other is empty. What would be the time it takes the bottles to reach the ground relative to each other?

5. The diagram below depicts a semicircular channel that has been securely attached, in a horizontal plane, to a table top. A ball enters the channel at “p” and exits at “r.” What would be the path of the ball as it exits the channel and rolls across the table? (Hestenes et al., 1992)

![Diagram of a semicircular channel]

6. A motorboat crosses a river, from point A to point B. Its engine speed is constant and the direction of its wheel is perpendicular to the riverbanks.
   1. One morning the boat left from point A and arrived at point B. On this day, the river was quiet, without any current whatsoever.
   2. On another morning, the same boat, again, was meant to cross the river from point A to point B. This time, however, a strong current swept the boat away, and it arrived at point C.

What would be the crossing time of the boat relative to first and second day?
Explanations for the Problems

1. One of the basic principles of the classical mechanics states that an object moves in the direction of the net force acting on the object. Therefore, the yo-yo moves in the direction of the pull. Although it seems that the yo-yo rollback, it is not possible in the demonstrated position of the yo-yo for two reasons. First, the center of the yo-yo should be hold still to make it spin around. Second, it is not possible for yo-yo to move forward or backward when its center is hold still – it only spins around in its original position.

2. The direction of the velocity of an object swinging in a circular path is always tangent to the circle at every point of the circle (see the figure below). When the string breaks at the ball, as stated in the problem, the ball would continue its path in the direction of the velocity at that point because there is no force acting on the ball after the string breaks, except for gravity (because the direction of the gravity is vertical and the demonstrated plane is horizontal to the earth, we do not need to think about the effect of gravitation). If there is no force acting on an object, the object would be either not moving or moving in a straight-line. In other words, the path of the ball would be a straight-line tangent to the circle at the breaking point because there is no force distracting the ball from its original direction.

3. As stated in the previous explanation, if there is no force acting on an object, the object would be either not moving or moving in a straight-line. The kick is a spontaneous act on the hockey puck—there is no force acting on the puck after the kick, except for gravity (we do not need to think about gravity because we are interested in the horizontal plane.) Because there is no continuous force acting on the puck, the puck would move in a straight-line. According to the strength of the kick, the puck would be distracted from its original direction—the stronger the kick, the larger the deviation is from its original direction.
4. All the objects experiencing a free fall have a constant acceleration, which is called “gravitational acceleration” and calculated as 9.8 m/s² on the earth. Therefore, any released object, whatever its weight is, would speed up with a constant acceleration; therefore, both bottles would have the same speed all the way down to the earth and they would reach the ground at the same time. It seems unusual to expect every object to have the same acceleration when they experience a free fall although the gravitational force acting on these objects are different. However, it is logical indeed. Let’s put it in this way: There are two objects—heavy one and light one, and the corresponding gravitational forces acting on these objects are stronger and weaker respectively. Here is the point; the acceleration not only depends on the force acting on the object but also on the mass of the object (F=ma or a=F/m) which means that while the acceleration is positively proportional to the applied force, it is negatively proportional to the mass. Consequently, in the case of heavier object/stronger gravitational force and lighter object/weaker gravitational force, the force and the mass compensate each other and result with a constant acceleration.

5. This problem is similar to the problem #2. The direction of the velocity of an object moving in a circular path is always tangent to the circle at every point of the circle. The same rule is valid for this semicircle channel too. When the ball exits the channel at point “r”, the ball would continue its path in the direction of the velocity at that point because there is not any force acting on the ball when it exits the channel, except for gravity (again, because the direction of the gravity is vertical and the demonstrated plane is horizontal to the earth, we do not need to think about the effect of gravitation). Therefore, the ball would follow a straight-line tangent to the semicircle at point “r” as demonstrated in the figure below.

6. In both days, the engine speed is constant and the direction of the wheel is perpendicular to the riverbanks. The only difference in the second day is the strong current. Because the current is perpendicular to the direction of the wheel, the vertical velocity of the boat does not change but the boat gains a horizontal velocity because of the current. Therefore, the direction of the boat is not perpendicular to the river anymore. However, we can still conceptualize the direction of the boat in terms of its
vertical and horizontal components. The time for crossing the river solely depends on the vertical component of the velocity. Because the vertical velocity of the boat is same for both days, the boat would cross the river in the same amount of time for both days.
APPENDIX D

INSTRUCTIONS FOR THE PROBLEM-SOLVING SESSIONS
Instructions for the Problem-Solving Sessions

The purpose of this session is to obtain information about your conceptual knowledge and the way you use it. In order to do this, I am going to ask you several problems. While you are solving the problems, please do not hesitate to communicate any idea passing in your mind and do not constrain yourself with any kind of expectations. The information collected through this session will be used solely for my research. Your name will not be released to anyone at anytime.

I would like you to work through a series of problems, and to “think aloud” as you are working on each problem. What I mean by think aloud is that I want you to say everything you are thinking from the time you first see the problem until you reach a solution. It is important for this study to obtain every detail of what you are thinking while working on the problem. Therefore, if you get silent for any long period of time I will ask you to talk. After you reach a solution, I will ask you several questions regarding your solution. We will begin with a couple of warm-up questions to get used to the think-aloud procedure.

Sample Problem: A rocket is moving along sideways in deep space, with its engine off, from point A to point B. It is not near any planets or other outside forces. Its engine is fired at point B and left on for two seconds while the rocket travels from point B to some point C. What kind of path does the rocket follow from B to C and after C.

(Please show your best guess for this problem even if you are unsure of the answer.) (Clement, 1983)
REFERENCES


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