AN ANALYSIS OF THE NATURE OF STUDENTS’ METACONCEPTUAL PROCESSES AND THE EFFECTIVENESS OF METACONCEPTUAL TEACHING PRACTICES ON STUDENTS’ CONCEPTUAL UNDERSTANDING OF FORCE AND MOTION

DISSERTATION

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By

Nejla Yuruk, M.S.

*****

The Ohio State University

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Dissertation Committee:

Professor Kathy C. Trundle, Co-advisor

Professor Christopher Andersen, Co-advisor

Professor Michael E. Beeth

Approved by

Co-Advisors

College of Education
ABSTRACT

This study had three aims: (1) to investigate the effectiveness of facilitating students’ metaconceptual processes, (2) to examine the durability of the impact of metaconceptual teaching on students’ conceptual understanding of force and motion, and (3) to gain insight into the nature of metaconceptual processes as the students participated in the metaconceptual teaching activities. In examining the nature of students’ metaconceptual processes, the purpose was to tease apart and categorize the types of metaconceptual processes, portray the trends within each type of metaconceptual process and describe the characteristics and the content of the metaconceptual processes related to students’ ideas that changed throughout the metaconceptual teaching interventions. A multi-method research design that incorporated experimental and case study designs was employed. While the experimental group was exposed to metaconceptual teaching interventions, in the control group the same science content was taught by tradition instruction.

The research was conducted in the two classrooms of a physics teacher. Participants of this study who were enrolled in one of the two physics classes involved 45 grade eleven and grade twelve high school students. In order to study the nature of students’ metaconceptual processes, three students from the experimental group were selected based on their background in physics and their pre-instructional conceptual
understanding of force and motion. While data of three students were used to describe the
characteristics and trends within each type of metaconceptual process, data of two
students were used for an in-depth analysis of their metaconceptual processes about their
ideas of force and one-dimensional motion.

Data from a variety of sources were collected to assess students’ conceptual
understanding of force and motion and their metaconceptual processes. In order to assess
students’ conceptual understanding of force and motion, Force Concept Inventory (FCI)
was administered to both groups prior to, following, and nine weeks after the
instructional interventions. Force and motion ideas of students who were the focus of the
intensive case studies were identified by conducting one-to-one semi-structured
interviews prior to and following the instructional interventions. The data regarding
students’ metaconceptual processes were derived from students’ journals, audio-
recordings of group-based activities, video-recordings of classroom discussions, and
interviews conducted following the instructional interventions.

In the experimental group, students’ engagement in metaconceptual knowledge
and processes was facilitated through various instructional activities (i.e., poster drawing,
journal writing, group debate, concept mapping, and class and group discussions). These
activities intended to encourage students in the experimental group (a) to become aware
of their existing and past conceptions, associated beliefs, everyday experiences and
contextual differences, (b) to monitor their understanding of the new conception, changes
in ideas and the consistency between their existing and new conceptions, and (c) to
evaluate competing conceptions by reflecting on the plausibility and usefulness of them.
In the control group, the main method of instruction was lecturing supplemented by laboratory experiments, demonstrations, and quantitative problem-solving.

In order to compare students in the experimental and control groups in terms of their conceptual understanding, Analysis of Covariance (ANCOVA) was generated. Students’ pre-instructional FCI scores were used as covariate to adjust the effect of instructional treatments on students’ conceptual understanding for differences in their conceptual understanding that existed prior to the instructional interventions. The results ANCOVA indicated that students who were exposed to metaconceptual teaching interventions had significantly better conceptual understanding compared to those taught by traditional instruction following the instructional interventions. The results of ANCOVA generated by using students’ delayed-FCI scores showed that students in the experimental group maintained their better conceptual understanding over a nine-week period. This finding points out the positive short- and long-term impact of facilitating students’ metaconceptual processes on students’ conceptual understanding.

In regard to the investigation of the nature of students’ metaconceptual processes, the results indicated that metaconceptual thought is multidimensional in the sense that it involves various types of processes that are qualitatively different in terms of the object of the processes and the information generated from them. When students are provided with structured opportunities, they engage in several types of metaconceptual processes ranging from becoming aware of ideas to making judgmental decisions about competing ideas. The results also showed that metaconceptual processes are multifaceted and interdependent, and occur at different levels of sophistication.
Dedication

This dissertation is dedicated to my mother, Gulseren, for her endless love, patience, and for all she has done for me, and to my daughter, Oyku, for the joy she brought to our life.
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My doctoral experience has been a very rewarding yet difficult journey. It has been full of challenges and endless rewards. On the path of this journey, there are many people who through their encouragement, guidance, and knowledge have made important contributions to this dissertation. It would be impossible to list everyone who contributed, or to adequately explain the extent of the contributions of those who are mentioned. Writing this dissertation has given me a vivid meaning to the acknowledgments I have seen in other dissertations. Phrases like "immensely thankful" and "deeply indebted" have real resonance now. The people who I mentioned in these acknowledgments should know how heartfelt and sincere my gratitude is.

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Dr. Kathy Trundle, who accepted the task of being my co-advisor after Dr. Beeth
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metacognition that he initiated gave me the starting point and provided me with the
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VITA

April 6, 1974. ....................................... Born – Ankara, Turkey

1997...................................................... B.S. Chemistry Education, 
Middle East Technical University, Turkey

1997-2000 ............................................ Research/Teaching Assistant, Department of 
Secondary School Science and Mathematics 
Education, Middle East Technical University, 
Ankara, Turkey

2000...................................................... M.S. Secondary School Science and Mathematics 
Education, Middle East Technical University, 
Ankara, Turkey

1999-present......................................... Graduate Student, The Ohio State University

PUBLICATIONS

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CHAPTER 1
INTRODUCTION

How do we understand the process of formal learning? More specifically, how do students derive meaning about the natural world? These questions have been the object of the concern of many philosophers, cognitive psychologists, and educators for centuries. Various theoretical models have been developed to explain the learning process. These theories not only provide explanatory frameworks for the learning process, but they contain strong implications for teaching practice that should improve students’ learning.

One of the theoretical models that has dominated research and teaching practices in science education for two decades is the Conceptual Change Model (Posner, Strike, Hewson, & Gertzog, 1982). Within the science education community, this model has been a leading theoretical framework that explains how students learn science conceptions that are different from their existing ones and has been interpreted by educators through instructional practices. Research that has roots in cognitive psychology has also produced theoretical frameworks about the nature of the change in students’ conceptions (Vosniadou, 1999). Regardless of different research traditions that explain change in learners’ conceptual knowledge, models of conceptual change make the “assumption about the importance of metacognitive awareness” (Pintrich & Sinatra, 2003, p. 432). White and Gunstone (1989) pointed out the importance of promoting
metacognition in facilitating conceptual change by saying that “If metalearning can be taught, then the problem of how to bring about conceptual change may be solved” (p. 581). It was the intent of this study to develop instructional interventions to facilitate students’ engagement in metacognitive processes and to better understand the nature of metacognitive processes as they participate in the developed instructional activities.

Theoretical Background

In the late 1970’s, views of learning began to shift away from a behaviorist towards a constructivist perspective that emphasizes the active role of learner in the learning process (Duit & Treagust, 1998; Mason, 2003). Educational practices based on behaviorist views of learning placed the responsibility of learning on the shoulders of the teachers, who are supposed to determine appropriate reinforcements that would promote the desired student behavior or punish students to extinguish their unwanted behaviors. However, this approach failed to explain why students weren't learning even though the instructional program provided the appropriate stimuli (Jones & Brader-Araje, 2002). Due to the failure of behaviorist educational practices to explain this aspect of learning process, constructivism has been found as an appealing alternative that is able to explain the complexity of the learning process (Duit & Treagust, 1998).

In contrast to the behaviorist view of transmission of knowledge from the teacher and the text to the learner, constructivists argue that learners do not passively acquire knowledge but actively construct meaning through their interpretive interactions with and experiences in the world (von Glasersfeld, 1989). Researchers’ recognition that students are not blank slates or empty vessels to be filled with knowledge but they bring with them
a rich array of prior experiences, knowledge and beliefs lead them to turn their attention to the identification of students’ conceptions in a variety of science topics (Duit, 1999).

The results of the studies that have been devoted to the identification of students’ conceptions in science domains showed that students come to the learning situations with existing conceptions about the world around them, which were labeled as preconceptions (Anderson & Smith, 1987), naïve beliefs (Caramazza, McCloskey, & Green, 1981), alternative frameworks (Driver & Easley, 1978; Driver & Erickson, 1983), intuitive ideas (Stavy, 1990) or misconceptions (Cho, Kahle, & Nordland, 1985; Griffiths & Preston, 1992). These existing conceptions, which are different from those accepted by the scientific community, exist even after formal instruction (Driver & Easley, 1978; Duit & Treagust, 1998). Existence of students’ alternative conceptions suggests that learning a new conception does not only involve addition of new information into existing knowledge structure, but it also involves a major restructuring in the existing conceptual system (Scott, Asoko, & Driver, 1992; Vosniadou & Brewer, 1987). This view of learning attracted the interest of researchers to seek theoretical models to explain the nature of change and the conditions under which the restructuring takes place.

**Learning as a Process of Conceptual Change**

In search for a theoretical framework to conceptualize learning of science conceptions, some science educators turned their attention to history and philosophy of science. The Conceptual Change Model (CCM) developed by Posner, Strike, Hewson and Gertzog (1982) has been one of the leading paradigms in science education research for many years. Posner et al. (1982) likened the change in individuals’ conceptions to
changes in the knowledge of scientific communities during a paradigm shift (Kuhn, 1970; Lakatos, 1970). Posner et al. (1982) has been also influenced by Toulmin’s (1972) notion of knowledge as occupying a “niche” within the “conceptual ecology.” According to this view, conceptions survive and have meaning in an ecological niche.

CCM, which describes learning as an interaction between new and existing conceptions, has two major theoretical components: (a) the conditions that need to be fulfilled for an individual to experience conceptual change, and (b) the individual’s conceptual ecology “that provides the context in which the conceptual change occurs and has meaning” (Hewson & Thorley, 1989, p. 541). These components are briefly described below.

There are four conditions that need to be satisfied before conceptual change can take place: (a) the learner must be dissatisfied with the existing conception, (b) the learner must find the new conception to be intelligible; (c) the learner must regard the new conception to be plausible, and (d) the learner must find the new conception to be fruitful, and the new conception must lead to new insights (Posner et al., 1982). The extent to which the conception is intelligible, plausible, and fruitful determines the status of a conception for the individual (Hewson, 1981; Hewson & Thorley, 1989). The degree to which an individual understands and finds the new conception believable and useful, the higher is its status compared to the status of existing conceptions. If a new conception is incompatible with an existing conception of higher status, the new conception will not be accepted until the relative status of the existing conception is lowered. Determining the status of a conception and comparing the status of competing conceptions require the
learner to think and reason about the conceptions and evaluate the relative ability of conceptions to explain the natural phenomenon.

The other component of CCM that is important in determining the status of a conception is the learner’s conceptual ecology. Learners’ conceptual ecology involves different kinds of knowledge and beliefs that act as an “ecological niche” (Strike, 1983) in which learners’ ideas survive and have meaning. Learners’ conceptual ecology, including epistemological commitments, metaphysical beliefs, anomalies, analogies, metaphors, and other knowledge, serves as a base for determining what counts as a valid explanation of a phenomena. In other words, the conceptual ecology provides the criteria for the learner to decide whether a given condition for the new conception is met or not. A fuller discussion of the conditions for conceptual change and of the elements of the conceptual ecology is provided in Chapter Two.

The view of learning presented in CCM provides an explanation of how learners might come to change their existing knowledge structure in a subject domain. The strength of CCM to explain the conditions under which conceptual change takes place has been acknowledged by many researchers (Duit, 1999; Vosniadou, 1999). It has inspired a great deal of research that focused on what teachers can do to manipulate the instructional context to support the change in individuals’ knowledge structure (Beeth, 1998; Driver, Asoko, Leach, Mortimer, & Scott, 1994; Duckworth, 1997, Hennessey, 1999). However, the nature of what is changing in the conceptual change process is not explicitly addressed in this model. By the mid-1990s several researchers began to take a closer look at the change process. Many researchers proposed different theoretical frameworks to explain the nature of the change in learners’ existing cognitive structure.
These theoretical frameworks about conceptual change differ mainly in terms of researchers’ assumptions about the nature of learners’ existing conceptual structure and the human cognition. While some of the researchers including Posner et al. (1982), diSessa (1993), Vosniadou (1994) and Chi, Slotta, and Leeuw (1994) assumed that knowledge acquisition occurs in the mind of individual, others, such as Linder (1993) and Ueno (1993) conceived it as a socially shared event between cognitive agents. Differences in their views regarding the nature of learners’ conceptual structure are described below.

Vosniadou (1994) claimed that concepts are embedded in and constrained by theoretical structures. She distinguished two theoretical structures: “framework theories” involve an individual’s compilation of ontological and epistemological presuppositions that are based on everyday experience and tied to years of confirmation whereas “specific theories” involve domain-specific interrelated propositions or beliefs that explain the properties and behaviors of physical phenomena. According to this view, conceptual change may take place concerning both frameworks theories and specific theories, but it is more difficult to achieve when it requires the revision of fundamental presuppositions of a framework theory.

In contrast to Vosniadou’s view of coherent theoretical structures, diSessa (1993) argued that the knowledge system of novices is weakly organized and fragmented. The fragmented knowledge pieces, which were called “p-prims” by diSessa, resulted from one’s superficial abstractions of his/her experiences in the world. Learners use p-prims like physical laws to generate explanations in particular situations. According to diSessa’s view, conceptual change occurs when there is a structural change in the
functions of p-prims from relatively isolated, self-explanatory entities to the pieces of an internally coherent conceptual system.

Another view of conceptual change is based on the idea of how concepts are organized. Chi et al. (1994) maintained that concepts belong to one of three ontological categories: matter, processes, or mental states. There are other subsets of these ontological categories. For example, matter can be separated into natural and artificial kinds, and subsequently, natural matter can be separated into living and non-living, etc. Conceptual change occurs when a concept is reassigned from one ontological category to another. Ontological category shift across ontological categories is more difficult than the shift within the same ontological category.

Conceptual change process described by Posner et al. (1982), Vosniadou (1994), diSessa (1993) and Chi et al. (1994) is conceived as an event that occurs only in the mind of an individual. Researchers who adopt a sociocultural view of learning emphasize that individuals’ alternative conceptions are not only the result of their cognitive system but they are socially formed and originate from socially negotiated “language games” (Ueno, 1993). The resistance of students’ alternative conceptions to change is due to an interactive social maintenance system. Ueno (1993) claimed that everyday discourse and scientific discourse differ in terms of “metacontext.” According to this view, conceptual change does not involve a modification in the cognitive system, but it is a process of differentiation between everyday and scientific discourse and clarification of metacontext.

Several theoretical frameworks have been proposed to explain the nature of the conceptual change process. A more detailed review of these theoretical frameworks is
provided in Chapter Two. These theoretical frameworks differ mainly in terms of their focus on the object of the change process. They highlighted the role of learners’ epistemological and ontological presuppositions, their “self-explanatory” everyday experiences and the context in the development of alternative conceptions. Although these various models or accounts of the change process differ in detail, they agree that the change involves a major restructuring of the existing knowledge structure during a learner’s attempts to reconcile the new information with the existing conceptual structure, and the outcome of the change process is a shift from the use of naïve theories or alternative conceptions to the use of more sophisticated theories and more scientifically acceptable accurate conceptions.

The theoretical frameworks proposed to explain change in learners’ conceptions suggest that achieving a change in the existing conceptual structure requires the learners to juxtapose the existing conceptions against new conception, to recognize, integrate and evaluate the existing and new conceptions and the associated commitments, everyday experiences and contextual factors. In other words, for achieving a major restructuring in existing conceptual structure, learners should (a) be aware of their existing conceptions, ontological and epistemological presuppositions, the context in which the conception is used, and their interpretations of everyday experiences; (b) monitor their comprehension of the new conception, and the consistency between the existing conception and the new conception; and (c) evaluate the relative status of the new conception in relationship to their existing conceptions. Awareness, monitoring, and evaluation are the key processes subsumed under the heading of metacognition. These processes are the main focus in
developing the instructional activities that aim to facilitate students’ metacognitive thought.

Metacognition and Conceptual Change

As the view of learning shifted towards a greater emphasis on the role of the learner, researchers started to acknowledge that learners are not only active in the construction of meaning, but they can also control and regulate their learning in a metacognitive manner. Researchers studying the change in students’ conceptions did not overlook the role of this characteristic of the learner in the conceptual change process. Many researchers acknowledged the intertwined nature of learners’ metacognitive activities and the change in their conceptions (Beeth, 1998; Ferrari & Elik, 2003; Hennessey, 1999, 2003; Vosniadou, 1994, 2003; White & Gunstone, 1989).

Metacognition is a very broad construct involving a wide range of knowledge and processes. Several researchers have used a variety of theoretical frameworks to describe and study this construct. Since its use by Flavell (1976) and Brown (1978), metacognition has become one of the most prominent constructs in cognitive and educational psychology. Fundamental aspects of metacognition, such as conscious access of knowledge and control of thinking, have appealed to many researchers from such diverse areas as reading comprehension, problem solving, memory development, cognitive development, and intelligence (Campione, 1987). Researchers’ interest in metacognition was especially triggered by the distinguishable metacognitive differences between expert and novice learners (Glaser & Chi, 1988; Sternberg, 2001), and between poor and effective learners (Campione, 1987). The promising results of the investigations that
aimed to improve students’ learning outcomes through enhancing metacognition have also attracted researchers to this construct (Baird, 1986; Gunstone & Mitchell, 1998; Hennessey, 2003; White, 1988).

Despite its widespread use and impacts in many areas of psychological and educational research, metacognition has been described as a “fuzzy concept” (Flavell, 1981, p. 37). According to Brown (1987), the term owes its vagueness to separate historical roots, to the difficulties in distinguishing metacognitive processes from cognitive processes, and to the use of a single term to describe a broader range of processes, skills and types of knowledge. Due to the multidimensional character of metacognition, a precise definition is subject to debate. Broadly, metacognition is defined as “one’s knowledge and control of own cognitive system” (Brown, 1987, p. 66). This construct has also been defined as “thinking about one’s own thinking” (Rickey & Stacy, 2000), one’s “inner awareness” about one’s learning process, what one knows or one’s current cognitive state (Hennessey, 2003), “knowledge about knowledge” or “reflections about actions” (Weinert, 1987). Kuhn, Amsel, and O’Loughlin (1988) described metacognition as “thinking explicitly about a theory one holds (rather than only thinking with it)” (p.7). Collectively, these definitions suggest that the key features of the knowledge and processes subsumed under the heading of metacognition are one’s acquired knowledge about cognition, online awareness of one’s stock of information, and control and regulation of one’s cognitive processes.

Various kinds of knowledge and processes have been identified as metacognitive in their nature. Theorists and researchers used different taxonomies to classify these knowledge and processes (see, for example, Brown, 1978; Chi, 1987; Flavell, 1979;
Kluwe, 1987; Schraw & Moshman, 1995). A detailed discussion of the components for each taxonomy is found in Chapter Two. Knowledge and processes, such as one’s knowledge about problem solving or reading strategies, and monitoring and regulating the execution of those strategies, awareness and employment of heuristics, one’s knowledge about the limitations of his/her memory or learning styles, have been acknowledged as metacognitive (see Brown, 1978; Flavell, 1979; Garner, 1987; Hacker, 1998; Schraw & Moshman, 1995). Although these forms of metacognitive knowledge and processes have potential to successfully perform a given task (Hennessey, 2003), they may not be enough to bring about a major restructuring in learners’ conceptual structure.

As the theoretical frameworks proposed to explain the change in students’ conceptions suggest, achieving a major restructuring requires that the learner (1) is aware of his/her own existing conceptions, commitments, experiences and the context in which the conception is used; (2) monitors the comprehension of new conception and the consistency between the existing conceptions and the new conception; and (3) evaluates the relative status of the new conception in relationship to their existing conceptions. In other words, the change in the learners’ conceptual structure requires metacognitive knowledge and processes that are acting on or related to the learners’ conceptual system. Since the term metacognition has been used as a blanket term that covers a wide range of knowledge and processes, it is fruitful to distinguish between metacognitive knowledge and processes that are acting on and related to one’s conceptual system from other metacognitive knowledge and processes. Thorley (1990) suggested that it is necessary to make a distinction between “metaconceptual” and “metacognitive” components of meta-
level thinking. In line with this suggestion, I will use the term metaconceptual to refer to metacognitive knowledge and processes that are acting on and related to one’s conceptual system. Hewson, Beeth and Thorley (1998) pointed out that processes such as “commenting on, comparing and contrasting these explanations, considering arguments to support or contradict one or another explanation, and choosing one of these possible explanations are metaconceptual activities” (p. 205) and are inherent in the conceptual change process.

Metaconceptual knowledge and processes involve only a portion of the total knowledge and activities that are metacognitive in their nature. Based on the key characteristics of metacognition that are an acquired knowledge about one’s cognition, awareness of one’s personal stock of information and one’s control and regulation of cognition, metaconceptual knowledge and processes can be classified into four components: metaconceptual knowledge, metaconceptual awareness, metaconceptual monitoring, and metaconceptual evaluation.

Metaconceptual knowledge is one’s stable and statable knowledge about concept learning and the factors influencing concept formation. This kind of knowledge is acquired through experience and stored in the memory. It can be retrieved from the memory explicitly or implicitly when needed. Metaconceptual awareness is one’s awareness of and reflection on existing and past concepts and elements of conceptual ecology, including one’s interpretation of experiences, ontological and epistemological presuppositions and the context in which a concept is used. The object of reflection is not a stored knowledge about concept learning, but it is the existing concept itself or epistemological and ontological commitments, context, and past experiences.
Metaconceptual monitoring and evaluation involve processes that a learner engages in during her/his attempts to learn a conception. Metaconceptual monitoring is an “online” process, which generates information about one’s cognitive state or thinking process. Examples of the monitoring processes are monitoring information coming from other people or sources, the comprehension of conceptions, the consistency between the existing and new conception, and changes in ideas. Metaconceptual evaluation involves learners’ judgmental decisions about the relative ability of the competing conceptions to explain the real phenomenon.

Rationale for the Study

One of the main aims of science teaching is to facilitate an understanding by students of natural phenomenon that is in line with the knowledge produced by the scientific community. However, it is well documented in the literature that many of the students’ ideas about natural phenomenon are immensely different from the scientific ones (Driver & Easley, 1978). Those strongly held alternative conceptions are the main source of the difficulties students and teachers encounter in learning and teaching science conceptions. The difficulty of students to move from a commonsense explanation of a natural phenomenon to a sophisticated and scientifically accepted one suggests that the acquisition of science conceptions requires extensive reorganization of the existing conceptual system (Vosniadou & Brewer, 1987). Studies have shown that even after formal instruction students retain their alternative conceptions (Duit & Treagust, 1998). The failure of the formal instruction to facilitate the reorganization in learners’ existing
conceptual structure points out the need to develop instructional interventions in light of the theoretical frameworks that explain the change in learners’ conceptions.

The CCM and other theoretical and research studies on conceptual change have provided a learning model and theoretical frameworks about the nature and conditions of the reorganization in learners’ conceptual system. Learning models not only explain the nature and mechanisms of learning process, but they may also have implications for instructional practices in various domains. They do not prescribe instructional activities that aim to facilitate learning; rather, they give educators an idea about what kinds of mental processes should be promoted through instruction to facilitate learning. The nature of the learning described in the CCM and in the other theoretical frameworks about the change in students’ conceptions underlined the role of metaconceptual knowledge and processes in the change process. Metaconceptual processes require the learner to engage in higher levels of thinking that are not easy to achieve through traditional instruction where conceptual change is often associated with compliance to the authority of the teacher and textbook. There is a need for designing instructional interventions in which students are assisted and encouraged to think about, monitor and evaluate their conceptions and the associated presuppositions and experiences. I call the instructional intervention designed to promote metaconceptual knowledge and processes “metaconceptual teaching.”

Metaconceptual teaching interventions do not intend to promote all kinds of metacognitive knowledge and processes but they focus on promoting metacognitive knowledge and processes that are related to or act on one’s conceptual system. Metaconceptual teaching aims to promote the following knowledge and processes:
1. **Metaconceptual Awareness:** Although students are good at interpreting their everyday experiences, their explanatory frameworks they constructed to explain the physical world and the presuppositions that constrain their explanatory frameworks may remain implicit and tacit (Vosniadou & Ioannides, 1998). They often are not aware of what they know nor are they aware of their presuppositions for their explanations. Students’ lack of metaconceptual awareness is not only related to their metacognitive abilities, but also to the instructional environment in schools. The instruction that goes on in most schools is based on making only the teachers’ view explicit. In order to promote students’ metaconceptual awareness it is necessary to create an instructional environment in which students’ are encouraged to explicitly express not only their existing conceptions but also epistemological and ontological presuppositions they use when interpreting their everyday experiences. Moreover, diSessa (1993) pointed out that novice learners might use case-based self-explanatory knowledge pieces to explain a phenomenon as if they are scientific principles. These phenomenological primitives resulting from learners’ superficial abstractions of their experiences are context-dependent. On the other hand, scientific principles are general principles that apply to different contexts. Therefore, learners’ ability to become aware their use of conceptions in different contexts is critical to their use of general scientific principles.

2. **Metaconceptual Monitoring:** The ability to monitor learning is one of the key characteristics of metacognitive activities. In order to consider a change from using alternative conceptions to scientific conceptions, the learner needs to
understand the new conception (Posner et al., 1982) and recognize that his or her existing conception is different from a new conception. In order to monitor the comprehension of a new conception and the consistency between existing ideas and ideas coming from other source, the learner should first monitor the information revealed by other people or other sources, such as textbooks and observations. Therefore, monitoring information coming from other people or sources, as well as understanding of the new conception and the consistency between existing and new conceptions are inherent in conceptual change. One of the common problems in science learning is students’ regression to their initial conceptions after a short time following instruction (Georghiades, 2000). Monitoring of the changes in ideas produces information for the learner about his/her current and past ideas. Learners who acquired information about the differences between their initial ideas and scientifically accepted current conceptions may be more likely to retain their current ideas. One of the aims of metaconceptual teaching is to help students monitor information coming from other peoples and sources, their understanding of the new conception, the consistency between their existing conception and the new information, and the changes in their ideas.

3. *Metaconceptual Evaluation:* Monitoring understanding of the conceptions and the consistency between existing and new conception is crucial in terms of meeting the intelligibility condition and recognizing the incompatibility between the existing explanatory framework and the new conception. However, these conditions alone do not guarantee the change in the status of competing
conceptions in terms of their plausibility and fruitfulness. Hewson (1981) maintained that conceptual change does not occur without concomitant monitoring of the relative status that is determined by the intelligibility, plausibility, and fruitfulness of the conceptions. The status of a conception rises as more conditions are met. A conception that is perceived as only intelligible has lower status than a conception perceived as intelligible, plausible and fruitful. The learner will not accept a new conception until the status of the existing conception is lowered. Hewson and Thorley (1989) asserted that evidence for the status of the conceptions cannot be ascertained from the content of the conception itself; rather, it should come from assessing learners’ comments “about” conceptions. Making comments about the relative status of conception requires the learner to make judgmental decisions about conceptions that can be called a metaconceptual evaluation. The evaluation process in the taxonomies about metacognition is associated with one’s ability to evaluate the usefulness of the strategy to achieve a goal (see Schraw & Moshman, 1995). Metaconceptual evaluation, on the other hand, is an evaluative process about the validity of conceptions. Metaconceptual teaching aims to provide students with a learning environment in which they are encouraged to evaluate the usefulness and validity of their existing and new conception to explain a physical phenomenon.

4. **Metaconceptual Knowledge**: One of the components of metacognition is an acquired knowledge about one’s own cognition or cognition in general. This knowledge is acquired through experience and stored in long-term memory. Metaconceptual knowledge refers to one’s stored knowledge about conceptual
learning and the factors influencing concept development. Flavell (1979) emphasized the dynamic interaction between the components of metacognition. Garner (1987) maintained that metacognitive knowledge provides a basis for metacognitive processes. Therefore, the quality and the existence of students’ metaconceptual knowledge play a key role in the enhancement and continuation of their metaconceptual processes. Gunstone (1991) noted that “Students very often have extremely transmissive views of learning and teaching, and very passive views of the role they should play in these processes” (p. 132). Students who possess a transmissionist view of learning are not likely to know that their existing conceptions may be different from those explained by the teacher, or their existing conceptions may influence their subsequent learning. Such a view of learning may not lead them to reflect on their existing conceptual structure or to monitor their understanding. One of the aims of metaconceptual teaching is to help students acquire knowledge about their conceptual learning through making their views of learning explicit during their attempts to learn conceptions.

An instructional intervention supported by metaconceptual teaching practices is based on an assumption that learners are capable of consciously controlling their own learning processes. According to this view, learners can be aware of the existence and nature of their conceptual system; monitor their understanding of the new conception, the consistency between existing and the new conception, and the changes in ideas; evaluate the validity of the conceptions, and decide whether or not to reconstruct their existing conceptual structure. All of these processes carry sophisticated metacognitive demands and are difficult to be engaged in by learners in a learning environment that does not
support these processes. This research attempts to design metaconceptual teaching interventions that aim to promote students’ engagement in metaconceptual knowledge and processes.

Although the impact of metacognition on the learning process has been acknowledged by various researchers, there have been only a limited number of research studies that investigated the role of metacognitive processes in changing students’ conceptions. Among the limited number of research studies, some of them focused on fostering students' independent learning through training for enhanced metacognition without giving attention to the particular metaconceptual processes listed above (Baird & Northfield, 1992), while some other researchers focused on students’ monitoring of the status of their conceptions by the use of the technical language of CCM (Beeth, 1998; Hennessey, 1991) and the nature of and the changes in students’ metacognitive capabilities over time (Hennessey, 1999). These studies provide us with evidence for the capabilities of young students to reflect on their existing conceptions and elements of their conceptual ecology and evaluate and monitor the status of new and existing conceptions. However, there is still a need for an empirical comparative research that investigates the effectiveness of an instructional design that is supported by metaconceptual teaching practices against the traditional instruction on promoting students’ conceptual understanding. Moreover, the studies that investigated the role of metacognition in promoting students’ conceptual understanding did not provide rich knowledge about the nature of metaconceptual processes. An in-depth research that takes a closer look at the nature of metaconceptual processes of individual learners in relation to the change in their conceptions is needed for a better understanding of individuals’
learning processes and potentially gives an idea for researchers and teachers about the ways to facilitate and improve metaconceptual processes.

One of the problems encountered in terms of changing students’ conceptions is the durability of newly acquired conceptions. Georghiades (2000) defined the term durability as an answer to this question “How long does a conception remain in effect, within the learner’s cognitive repertoire?” (p. 124). He pointed out that over an extended time span there may be regression to initial conceptions. The study conducted by Galili and Bar (1992) showed that the same students who used the scientific concepts to perform familiar tasks about force and motion reverted to pre-Newtonian reasoning after a short time while solving unfamiliar questions. Since the new conception is constructed on the existing conceptions, the durability of the new conception is critical to the learning of subsequent conceptions. Georghiades argued that “metacognitive instruction” may potentially have positive impact in dealing with the problem of durability of the conceptions. Learners’ awareness of their existing presuppositions and experiences facilitated through metaconceptual teaching practices may lead to a less fragile restructuring of learners’ conceptual system. A change in learners’ conceptions without an awareness of the presuppositions or rationales in adopting a conception will only be a surface-level modification and may not last long. Moreover, monitoring changes in ideas may produce information about the differences between past and current conceptions, which may be available for learners when they attempt to provide explanations for a phenomenon. This knowledge may prevent learners from regressing to their initial ideas. Therefore, one’s engagements in metaconceptual processes may potentially enhance the
durability of the conceptions. There is a need for empirical research that investigates the
effect of metaconceptual teaching practices on the durability of the conceptions.

Statement of the Research Problem

The effectiveness of the metaconceptual teaching interventions was examined in
terms of three outcomes: (a) students’ conceptual understanding; (b) the nature of
students’ metaconceptual processes in relation to their conceptual understanding; and (c)
the durability of the impact of metaconceptual teaching interventions on students’
conceptual understanding over a period of time. The specific research questions answered
through this research are:

1. What are the effects of metaconceptual teaching practices on students’
understanding of force and motion concepts?
2. What are the effects of metaconceptual teaching practices on the durability of
students’ understanding of force and motion concepts?
3. What is the nature of the metaconceptual processes students engage in during the
metaconceptual teaching practices in relation to their conceptual understanding of
force and motion?

Significance of the Study

Researchers’ attempts to explain the nature of the learning processes have much
more value if they are translated into effective instructional practices. This research aims
to translate theoretical accounts on the conceptual change process and learners’ ability to
control their cognition into an effective classroom instruction. In terms of this
characteristic, this research has potential to inform teachers and teacher education
programs about the teaching strategies used to promote students’ engagement in metaconceptual processes to facilitate science concept learning in the classroom settings. This research has also potential to contribute to a better understanding of the individual students’ metaconceptual processes in relation to the change in their conceptions. A better description of the students’ metaconceptual processes may lead to an enhanced understanding of the nature of learners’ science learning and ways of improving teaching practices to promote metaconceptual processes and science learning. Therefore, this understanding may have strong implications in the improvement of students’ science learning and instructional practices.

Overview of the Dissertation

In the next Chapter, the theoretical underpinnings of this study are described. A review of research and theoretical accounts related to this study is provided in four major areas: (a) students' conceptions of the natural phenomena; (b) constructivism; (c) conceptual change learning; and (d) metacognition. After presenting different theoretical perspectives that explained and categorized the construct metacognition, a taxonomy is introduced that classifies and identifies the metacognitive knowledge and processes that are related to concept learning and acting on one’s conceptual structure.

In Chapter 3, the methods of this study are portrayed. This includes a discussion of the participants, the context under which this study was conducted, the specifics of the research design, and data sources that were used to answer the research questions. Moreover, the nature of the instructional activities that were employed in this study was explained, and the procedures that were followed during collecting and analyzing data are
summarized. In the final section of this Chapter, validity issues and limitations of this study are discussed.

Chapter 4, which is devoted to the description of the results of data analyses, has two major sections. In the first section, results of quantitative analyses generated to answer research questions one and two are explained. It involves a description of both descriptive and inferential statistics generated to compare conceptual understanding of students who were exposed to metaconceptual teaching interventions with those taught by traditional instruction. The second section is devoted to the results of the analysis of qualitative data collected to answer research question three. This section is further divided into two major parts. In the first part, the types and the science content of metaconceptual processes that are related to the science ideas of two students selected from the experimental group are described. In doing so, the change in each student’s ideas related to force and one-dimensional motion is summarized and each student’s metaconceptual processes related to their science ideas identified before and after the instructional interventions were portrayed. In the second part this section, the nature of and trends in each type of metaconceptual process of three students are described.

In the final Chapter, the conclusions from this study are described in terms of the each research question. Moreover, implications of this study for instruction and educational research are discussed and, finally, suggestions for future research are provided.
CHAPTER 2

LITERATURE REVIEW

Overview of the Chapter

The three purposes of this study, namely (a) revealing the nature of metaconceptual processes, (b) comparing the effectiveness of metaconceptual teaching on students’ conceptual understanding with that of traditional instruction, and (c) investigating the durability of the impact of metaconceptual teaching on students’ conceptual understanding, rest on a body of literature that has emerged within the last several decades. The purpose of this Chapter is to provide a theoretical context within which this research was situated by building upon that literature. The primary fields of research relevant to this study originated in four major areas: (a) students' conceptions of natural phenomena in physics; (b) constructivism; (c) conceptual change learning; and (d) metacognition.

A review of the extensive body of literature related to these four major research areas is neither possible nor practical within the limits of this dissertation. For the purpose of understanding the context of this study, only a review of literature that is relevant to this study is presented in this Chapter. First, a brief review of literature on students’ conceptions about force and motion is presented, along with a review of the instructional research studies that addressed students’ conceptions. Second, constructivist
perspective on learning that provides a broader theoretical base for learning of science is described. Third, a review of theoretical accounts that explain the change in students’ conceptions is provided. Fourth, different theoretical perspectives to explain the construct metacognition are provided, and a taxonomy that classifies and identifies the metacognitive knowledge and processes that are related to concept learning and that are acting on one’s conceptual structure is introduced. Related to this area, a review of educational research studies that aim to promote students’ conceptual understanding through facilitating their metacognitive processes is presented.

Students’ Conceptions in Science

Over the last thirty years, an active research literature regarding students’ conceptual understanding in science has been established. This research has provided the science education community with detailed information about students’ conceptions of natural phenomena at various ages and in a wide range of science topics including mechanics, electricity, particles, optics, energy, heat, astronomy, and various other areas (Duit, 1993). According to Duit (1993), the “most powerful and fruitful driving force in research on students’ (and teachers’) conception” has been the constructivist views of learning. It is well established that students do construct their understandings of natural phenomena from all of their experiences, in school and out.

In early research regarding students’ conceptions, science educators treated students’ conceptions topic by topic and in isolation from other aspects of learning such as metacognition (Duit & Treagust, 1998). A great deal of literature on students’ conceptions at various content levels has been reviewed and cataloged in several
conference reports (Duit, Goldberg, & Niedderer, 1992; Helm & Novak, 1983; Novak, 1987), bibliographies (Carmichael, Driver, Holding, Phillips, Twigger, & Watts, 1990; Pfundt & Duit, 1991), books (Driver, Guesne, & Tiberghien, 1985; Driver, Squires, Rushworth, & Wood-Robinson, 1994; Osborne & Freyberg, 1985), and articles (Driver & Erickson, 1983; McDermott, 1984), These sources contain a comprehensive collection of research studies that documented students’ conceptions in a variety of science topics.

A majority of the studies identified immediately above have provided ample evidence that students’ conceptions in many fields of science are substantially different from the contemporary views of scientists, and most of these conceptions are held strongly and resistant to change. These conceptions have been labeled as “children’s science” (Gilbert, Osborne, & Fensham, 1982; Osborne, Bell & Gilbert, 1983), “alternative frameworks” (Driver & Easley, 1978; Driver & Erickson, 1983), “naive beliefs” (Caramazza, McCloskey, & Green, 1981), “preconceptions” (Anderson & Smith, 1987), and “misconceptions” (Cho, Kahle, & Nordland, 1985; Griffiths & Preston, 1992). In this study, I will use the term “alternative ideas” to refer students’ conceptions that are not consistent with contemporary scientific views of natural phenomena.

The impacts of students’ preexisting conceptions on teaching and learning science have been acknowledged by several science education researchers (Dekkers & Thijs, 1998; McDermott, 1991; Wandersee, Mintzes, & Novak, 1994). The resistance of students’ preconceptions to contemporary views of science constitutes a significant problem in teaching and learning science. Research studies showed that students’ difficulties in learning science stem from students’ preexisting conceptions about natural phenomena that are not consistent with scientifically accepted ones (Champagne,
Gunstone, & Klopfer, 1985; West, Fensham, & Garrard, 1985). Students learn science conceptions only to a limited degree and they sometimes continue to hold their preexisting conceptions (Duit & Treagust, 1998). Woods and Thorley (1993) maintained that students revert to their alternative conceptions even after “powerful” instruction:

In analyzing case-study evidence for students' understanding before and during instruction and finally about two months later, it has become clear to us how enormously difficult it is to help a student achieve a deep and robust understanding. Lessons which had seemed powerful and successful at the time appeared rather less so when the later interviews revealed that students had reverted to earlier naïve conceptions, could remember the 'right answer' but not justify it, or, in some cases, had seriously misconstructed key aspects of a lesson. (p. 25)

In summary, this body of research has shown that students do not come into classrooms without any preexisting knowledge about the natural phenomenon to be taught but they already hold deeply rooted conceptions and ideas that are not in harmony with the contemporary scientific views and that are resistant to instruction. Of the literature regarding the students’ conceptions, studies that identified students’ conceptions of force and motion are significant to this study, as force and motion was chosen as the scientific domain for this study.

*Students’ Alternative Ideas of Force and Motion*

Many research studies that investigated students’ conceptions about mechanics have been carried out since the 1970’s. By 1993, over 300 studies had been conducted on students' conceptions in mechanics alone, including the topics of force and motion; work, power, energy; acceleration; gravity; pressure; density; floating; and sinking (Duit, 1993). For the purpose of understanding students’ conceptual understanding of force and motion concepts, a number of research studies are reviewed below.
In a study with university students, Clement (1982, 1983) found that many students used pre-Newtonian ideas to explain the motion of objects in different situations. He reported that students have mental models for the relationship between force and motion based on their own intuition about how objects move in the world. Clement (1982, 1983) noted that students’ intuitive ideas conflict with Newton’s Second Law (F=ma) because students do not recognize friction as a force. Students believed that “continuing motion, even at constant speed, implies the presence of a continuing force in the same direction, as a necessary cause of motion” (Clement, 1983, p. 326). This alternative idea was referred as “motion implies a force” misconception. Clement (1983) pointed out that this preconception did not disappear after students completed a physics course. He added that during instruction "Newtonian ideas are simply misinterpreted or distorted by students so as to fit their existing preconceptions; or they may be memorized separately as formulas with little or no connection to fundamental qualitative concepts" (p. 335).

Halloun and Hestenes (1985a) constructed a diagnostic instrument (Mechanics Diagnostic Test) to identify concepts of force and motion held by college students enrolled in physics courses. They conducted interviews with 22 students within one month after they have taken the test. Halloun and Hestenes (1985b) developed a taxonomy of students' common-sense concepts about motion. They reported that students' conceptions were similar to the ideas of Aristotle (Aristotelian physics) and Buridan (Impetus physics). The results showed that students hold the idea that in the absence of forces, every object remains at rest. Students also believed that motion of an object is started by a force applied to it by an external agent and motion is sustained by an internal
force (impetus) in the object. Alternative conceptions about Newton’s Third Law were also common among the students. They hold the conceptions that the greater mass exerts the greater force or the object which causes motion of the other exerts the greater force, because it overcomes the other's opposition. They also tended to hold the conception that acceleration is due to increasing force. The study also showed that the students possessed a variety of ideas about gravity that were not associated with the Newtonian framework of motion. Students did not necessarily view gravity as a force. The conception that 'heavier objects fall faster' was common among them.

McCloskey, Caramazza, and Green (1980) investigated 47 undergraduate university students' conceptual understanding of force and motion. Among these students, 15 had never taken a high school or college physics course, 22 had completed one high school physics course, and 10 had completed at least one college physics course. The results revealed that many students, including those who had taken a physics course, held the conception that an object that is passed through a curved tube continues in curved motion after it exists the tube. Some students expressed the idea that the more dramatic the curvature of the tube (or the longer the object is in the curved tube), the more curved its motion will be after it emerges.

McCloskey (1983) asked college students qualitative conceptual questions to probe their understanding of forces acting on objects in different contexts such as a ball leaving a spiral snail track, a moving plane releasing a bomb, a ball rolling off a cliff, and a pendulum. The results of the interview showed that 11 of the 13 subjects expressed concepts associated with “naive impetus theory” (p. 306, italics in the original). Students who held this conception believed that “the act of setting an object in motion imparts to
the object an internal force or ‘impetus’ that serves to maintain the motion” (p. 306, italics in the original). Moreover, they believed that moving objects slow down and stop due to the dissipation of impetus. Students used this naive impetus theory to explain the behavior of objects in various situations. For example, for the problem in which a moving ball goes over the edge of the cliff, many subjects expressed that the ball would move in an arc for some time and thereafter fall straight down. This response pointed out students’ idea that the ball’s impetus keeps the ball moving horizontally for some time until the original impetus is entirely gone.

Sadanand and Kess (1990) studied conceptual understanding of 57 high school senior students. They identified three common alternative ideas: (a) animate objects must exert a force to hold things up, but inanimate objects do not have to do so; (b) a constant force is necessary to maintain a constant motion; and (c) reaction forces are less "real" than action forces.

Minstrell (1982) studied high school physics students’ conceptions about objects at rest. He found that a significant number of the students ignored the normal force acting on an object sitting on table. Driver, Squires, Rushworth, and Wood-Robinson (1994) reviewed a number of studies on students’ conceptions of force and motion. Driver et al. (1994, p. 149) summarized students’ main ideas about force and motion from the research studies as follows:

a. If there is motion, there is force acting;
b. If there is no motion, then there is no force acting;
c. There cannot be a force without motion;
d. When an object is moving, there is a force in the direction of its motion;
e. A moving object stops when its force is used up;

f. A moving object has a force within it which keeps it going;

g. Motion is proportional to the force acting;

h. A constant speed results from a constant force.

In summary, the results of these research studies on students’ conceptions of force and motion indicate that students across age levels hold conceptions that are incompatible with Newton’s Laws. Impetus-like beliefs held by students to describe the forces acting on objects in various situations are common among the students. Studies regarding students’ conceptions of force and motion provided a rich knowledge base about students’ conceptual understanding at content level. Although these studies identified the scope of the problem at the domain-specific content level, they have not addressed cognitive and metacognitive aspects of concept learning.

**Instructional Research that Addressed Students’ Conceptions**

The findings of research studies carried out on students’ conceptions about natural phenomena have inspired a great deal of research regarding what teachers can do to manipulate the instructional context to support the change in individuals’ knowledge structure. Several research groups or individual researchers developed instructional approaches to address students’ alternative ideas.

Scott, Asoko, and Driver (1992) reviewed studies investigating different teaching strategies that aimed to change students’ preconceptions with scientific views. They identified two main grouping of teaching strategies. The first group includes strategies dealing with cognitive conflict and their resolutions. This teaching approach involves
eliciting students' ideas and challenging those ideas by exposing them to situations in which their predictions are likely to be incorrect. The second group entailed strategies that provided different ways to help learners build scientific ideas upon their existing ideas. This group of teaching approaches involves the use of metaphors and analogies.

Cognitive conflict has been used as the basis for developing a number of teaching strategies that require students to resolve differences between their existing ideas and the scientific conception (see, for example, Champagne, Gunstone, & Klopfer, 1985; Cosgrove & Osborne, 1985; Nussbaum & Novick, 1982; Rowell & Dawson, 1985). Although they suggested different teaching sequences, they mainly emphasized making students’ preconceptions explicit, creating cognitive conflict with students’ preconceptions, and encouraging students to accommodate scientifically accepted views about natural phenomena.

For example, Champagne et al. (1985) designed a dialogue-based strategy that they called Ideational Confrontation. This teaching approach, which was specifically designed to alter students' alternative ideas within a particular domain, involves the following steps: (a) students are asked to be explicit about the notions they use to explain, or make predictions about a common physical situation; (b) each student develops an analysis that supports his or her predictions and presents it to the class; (c) students with different interpretations attempt to convince each other of the validity of their ideas; (d) the instructor demonstrates the physical situation and presents a theoretical explanation using science concepts; (e) further discussions allow students to compare their analyses with the scientific one. Champagne et al. (1985) investigated the effectiveness of this strategy in two groups: academically gifted middle-school students and university science
graduates preparing to become high school science teachers. The researchers found that the ideational confrontation strategy was successful in producing changes in both groups' understanding of force and motion.

Clement, Brown, and Zeitsman (1989) noted that not all preconceptions are misconceptions. According to them, students also hold ideas that typically align with physicists' views. These ideas, which were called “anchoring conceptions” may serve as targets of "bridging analogies." According to this teaching approach, the teacher uses bridging analogies to help students span the conceptual gap between anchoring and misunderstood conception (Brown & Clement, 1989).

The bridging analogy strategy involves a series of analogous demonstrations that are presented sequentially for comparison. For example, Clement (1993) attempted to use analogies to overcome the notion that an inanimate tabletop cannot provide an upward force on a book. He drew an analogy between the tabletop and a spring and then asks the students if a hand pushing down on a spring is analogous to the book pushing down on the table. The results showed that most students were unwilling to compare the tabletop and the spring because the students did not see the two objects as being physically similar. Clement used a series of bridging analogies between what the students accepted (hand on the spring) toward the unacceptable (book on the tabletop). For example, he showed a book on a piece of foam and then onto a thin piece of plywood. Finally he placed the book on the tabletop and asked the students if the case was similar. Use of this strategy to overcome students’ alternative ideas produced significantly greater pre-post test gains compared to the control group.
In 1984, Children’s Learning in Science (CLIS) research group at the University of Leeds initiated a research project in teaching and learning for promoting students’ conceptual understanding of science in classroom settings. This research project involved researchers from the CLIS research group and the local high school science teachers in the UK. Researchers and teachers worked collaboratively to explore ways of improving students’ conceptual understanding in various science topics, such as plant nutrition, particulate theory of matter, and energy (Scott & Driver, 1998). Although the type of instructional activities differed from topic to topic, they were designed to elicit students’ existing conceptions, differentiate conceptions (e.g. heat and temperature, and weight and mass), provide experiential bridges that allow students to make sense of particular scientific ideas, and present explicitly that scientists have a different view about the topic under investigation.

Although these teaching approaches followed different teaching sequences and used different instructional activities, they all assume that students come into classrooms with already structured ideas about the content of the lesson, and students can be taught or facilitated to compare their existing ideas with the scientific conception. Some of these teaching approaches highlighted students’ awareness of existing conceptions and comparison of existing conceptions with scientific views. These processes involve meta-level thinking. However, they did not provide a knowledge base about the nature of the meta-level processes.
Constructivism

Theoretical frameworks that describe change in learners’ conceptual understanding explain learning from a constructivist view. According to Duit and Treagust (1998), “conceptual change has become a term that denotes key aspects of mainstream constructivist approaches of the 1980s and early 1990s” (p. 10).

Constructivism is a theory of learning (knowing) and knowledge; it is an epistemological stance. It describes what “knowing” is and how one “comes to know” (Fosnot, 1996, p. ix). The roots of constructivism are attributed to the work of Jean Piaget (Good, Wandersee, & Julien, 1993).

Constructivism comes in various forms based on the philosophical perspective at its root, such as radical constructivism and social constructivism. Although the meaning of constructivism varies according to one's perspective and position, the common premise shared by different constructivist perspectives is a "view of human knowledge as a process of personal cognitive construction, or invention, undertaken by the individual who is trying, for whatever purpose, to make sense of her social or natural environment" (Taylor, 1993, p. 268). In other words, knowledge is not viewed as a true copy of reality, but as construction of the individual. Therefore, knowledge is not viewed as something that exists outside of the learner.

According to constructivist view, individuals actively construct knowledge through their life experiences and in the light of their interactions with their physical and/or social environment. von Glasersfeld (1996, 1998) argued that knowledge is actively constructed by the learner. According to him, the construction of knowledge
should be thought of as having an adaptive purpose, to help us operate in the world, rather than as the discovery of an underlying reality.

Constructivists reject the view of learning that is equated with a mere transmission of information from teacher to student. Though constructivism is not a theory of teaching, it suggests a different approach to instruction from that where the teacher is the “autocratic knower” and the learner is “the unknowing, controlled subject studying to learn what the teacher knows” (Fosnot, 1996, p. ix). Constructivists assume that knowledge cannot merely be transferred to a passive receiver from another individual; it must be constructed by each individual (von Glasersfeld, 1993). Since “learners are not empty vessels waiting to be filled” with knowledge (Driscoll, 2000, p. 376), what they already know is regarded as a major determinant of their subsequent learning. Constructivism attributes a critical importance to learner’s prior knowledge because learners make sense of new situations in terms of their existing understandings (Naylor & Keogh, 1999). The implications of this perspective for classroom practices address the need to take into account students’ intellectual environment, including their existing conceptions, presuppositions and experiences.

Conceptual Change Learning

Recognition that students bring to the science classrooms alternative ideas that are robust and difficult to extinguish through teaching led researchers to search for theoretical frameworks to explain how learners restructure their existing conceptions. Researchers from different study areas (science education and cognitive/educational psychology) have proposed different theoretical frameworks to explain the nature of
students’ preconceptions and describe how students change their preconceptions with scientifically accepted ones.

**Conceptual Change Model**

A Conceptual Change Model (CCM) was developed by Posner, Strike, Hewson, and Gertzog (1982) to provide explanations for how individual’s existing conceptions change when confronted with a new conception. Since its development, the theoretical framework of CCM has been widely applied in the science education community (Duit, 1999).

The view of learning presented in CCM is based on an analogy between knowledge construction in scientific communities and in individual learners, a view derived from the work of philosophers and historians of science such as Kuhn (1970), Lakatos (1970), and Toulmin (1972). Thus, the initial CCM assumes that learners behave like scientists when confronted with new information.

According to CCM, a new conception can be incorporated into the cognitive structure in two ways: If the learner knows little about the newly presented concept, or the new information is reconcilable with the existing conceptual structure, the new information can be incorporated with the existing ideas. This process was referred as “assimilation” by Posner et al. (1982) and “conceptual capture” by Hewson (1981). On the other hand, the learner may have a well-developed conception about the learning task, which may conflict with the new knowledge. In order to accept the new knowledge, the learner has to restructure her/his existing conceptions. This process was called “accommodation” by Posner et al. (1982) and “conceptual exchange” by Hewson (1981).
The main focus of CCM presented by Posner et al. (1982) was to clarify how accommodation takes place.

There are two major theoretical components of CCM: (a) the conditions that need to be fulfilled for an individual to experience accommodation, and (b) individual’s conceptual ecology “that provides the context in which the conceptual change occurs and has meaning” (Hewson & Thorley, 1989, p. 541). Although the initial CCM was further elaborated (Hewson, 1981; Strike & Posner, 1992), the theoretical components of CCM have remained as presented in the original theory.

Conditions of Conceptual Change

According to Posner et al. (1982, p. 214), there are four conditions that need to be satisfied before conceptual change can take place: (a) the learner must be dissatisfied with the existing conception, (b) a new conception must be intelligible; (c) a new conception must be plausible, and (d) a new concept must be fruitful. The conditions apply to the learners’ already existing conceptions or the new conception that they consider (Hewson & Thorley, 1989).

A conception is intelligible to the learner when s/he can comprehend the meaning of the conception or can identify or construct a coherent representation of the conception. According to Posner et al. (1982), intelligibility requires “an understanding of the component terms and symbols used and the syntax of the mode of expression” (p. 216). However, intelligibility requires more than just understanding what the words and symbols mean. Intelligibility also requires the learner to internally represent the conception “in the form of propositions, images or networks of interrelated propositions
and/or images” (p. 216). In other words, finding a conception intelligible entails identifying and constructing a coherent representation of the concept (Hewson, 1981).

For example, consider the following sentence: “He was climbing the mountain when he was at home sitting in the chair.” Although this sentence contains words each of which has meaning individually, the ideas implied by the words are not related in a meaningful and coherent way. It is not physically possible to climb the mountain and to be at home at the same time. Thus, it is impossible for the learner to represent this sentence in a meaningful form. Therefore, this sentence cannot possess any intelligibility for the learner.

Plausibility can be achieved when the learner perceives the new conception to be believable based on her/his existing knowledge about the world. In other words, a conception is plausible in the sense that the learner can rationally incorporate the new conception into her/his existing conception of the world. Plausibility depends on the extent to which the learner can create representation for the conception which “matches one’s sense of what the world is or could be like” and s/he finds “the new conception capable of solving problems of which one is aware” (Posner et al., 1982, p. 216). Posner et al. described plausibility as the “result of internal consistency with other knowledge” (p. 214). They maintained that a conception possesses plausibility if the learner perceives it to be consistent with her/his metaphysical belief, epistemological commitments, other theories of knowledge, and past experiences. According to Hewson (1981), a conception can be perceived to be plausible if it matches with the “personal standards of knowledge” (p. 50), such as elegance, parsimony, and economy.
Another condition that must be satisfied for conceptual change to occur is
fruitfulness. A conception is fruitful if it has the ability to solve a problem or to suggest
application to a variety of situations. Posner et al. (1982) noted that a new conception is
perceived to be fruitful if it “not only resolves its predecessor’s anomalies but also leads
to new insights and discoveries” (p. 222). Thus, a fruitful conception achieves something
of value for the learner (Hewson & Thorley, 1989).

Finally, in order for learner to consider changing a conception, the learner must be
dissatisfied with the existing conceptions. Dissatisfaction with an existing conception can
be experienced either due to the failure of an existing conception to explain an anomalous
event or due to its incompatibility with “epistemological standards, such as appearing
inelegant or clumsy, or containing *ad hoc* assumptions, or being unnecessarily
complicated” (Hewson, 1981, p. 387, italics in original). According to Hewson and
Thorley (1989), a person becomes dissatisfied with a conception “when it loses
plausibility or fruitfulness or both” (p. 542).

Chinn and Brewer (1993) argued that learners might not always be dissatisfied
with their existing conceptions even though they are confronted with anomalous data.
Chinn and Brewer suggested that when new data conflict with an existing theory (Theory
A), an individual may respond in seven different ways: (a) ignore the data; (b) reject the
data because of methodological flaws, random error, or alleged fraud; (c) exclude the
data from the domain of Theory A by asserting that Theory A is not intended to explain
the data; (d) hold the data in abeyance, promising to deal with it later; (e) accept but
reinterpret the data to make them consistent with Theory A; (f) accept the data and make
minor, peripheral changes to Theory A; and (g) accept the data and change theories,
possibly to Theory B. Only the last response results in changing one’s existing conception with the new conception.

In addition to dissatisfaction with the existing conception that leads to the change of an existing conception with the new one, Hewson (1981) pointed out the possibility that dissatisfaction with the new conception may prevent the assimilation of the new conception into the existing conceptual structure. Dissatisfaction with the new conception may be experienced if the new conception is irreconcilable with the firmly held existing conceptions with which the learner makes sense of the world, if the implications of new conception are unacceptable, or if the experimental or logical basis for the new conception appears doubtful.

Hewson (1981) expanded the CCM by building the notion of status, which was identified as the “hallmark” of conceptual change (Hewson & Lemberger, 2000). Hewson and Thorley (1989) defined status as the extent to which the conception is intelligible, plausible, and fruitful. They claimed that conceptual change is about raising and lowering the status of the existing and new ideas. Thus, learning a new conception means that its status rises.

According to Hewson (1981), in order for a conception to have any status, the learner must perceive it at least as intelligible. The learner may consider a conception as (a) intelligible, (b) intelligible and plausible, and (c) intelligible, plausible and fruitful. The status of the conception rises as more conditions are met. A conception that is perceived as only intelligible but not plausible or fruitful has lower status than a conception perceived as intelligible, plausible and fruitful. In other words, the status of a conception increases as the conditions are satisfied in the following order: intelligible;
intelligible and plausible; intelligible, plausible, and fruitful. Hewson (1981) suggested that the status of the new conception and the status of the existing conception together determine whether the learner may consider changing a conception s/he holds. If a new conception is irreconcilable with the existing conception, the learner can only accept the new conception when the status of the existing conception is lowered. In other words, if the new conception conflicts with an existing conception it cannot be accepted until the plausibility or fruitfulness of the existing conception is lost.

**Learner’s Conceptual Ecology**

The other theoretical component of CCM is a learner’s conceptual ecology, which deals with different kinds of knowledge that learners hold. The metaphor “conceptual ecology” was introduced by Toulmin (1972) as an analogy between biological and intellectual environments. The environmental characteristics of an ecological niche influence the natural selection occurring within its bounds. Similarly, the elements of the intellectual environment of individuals affect the cognitive operations within its bounds. The learner’s conceptual ecology “provides the context in which conceptual change occurs and has meaning” (Hewson & Thorley, 1989, p. 541). Posner et al. (1982) identified the components of conceptual ecology as (a) anomalies, (b) analogies and metaphors, (c) epistemological commitments, (d) metaphysical beliefs and concepts, and (e) other knowledge.

Acceptance or rejection of a conception happens within the realm of conceptual ecology. The components of conceptual ecology provide a framework for determining the extent to which the conditions are met. In other words, learners use the existing
knowledge in their conceptual ecology to decide whether different conditions are met, that is whether a new conception is intelligible (understanding what it means), plausible (believing it to be true), and fruitful (finding it useful).

Posner et al. (1982) emphasized the role played by the components of conceptual ecology in conferring initial plausibility on a conception. They argued “initial plausibility can be thought of as the anticipated degree of fit of a new conception into an existing conceptual ecology” (p. 216). They suggested that in order for the learner to consider a conception as plausible the conception must be consistent with the components of conceptual ecology. The learner’s conceptual ecology is important in determining the status of a conception because it provides the criteria for the learner to decide whether a given condition is met. In this regard, individuals’ epistemological commitments and metaphysical beliefs and concepts about science play a critical role in determining the status of the new and existing conceptions.

To sum up, learners who find a new idea intelligible, plausible, and fruitful and who are dissatisfied with their existing idea experience a change of their existing idea with the new one. Dissatisfaction with an existing idea requires the learner to become aware of his/her existing conception (Sinatra & Pintrich, 2003) and monitor his/her learning so that s/he can realize the inconsistency between existing conceptions and anomalous data. Thinking about the intelligibility of a new idea requires learners to monitor their understanding of the new idea. Judging whether a new conception is intelligible, plausible, or fruitful requires reflection about ideas (Sinatra & Pintrich, 2003). Comparing the plausibility and fruitfulness of existing and new conception demands the learner to engage in an evaluation process in which they make decisions
about the validity and usefulness of ideas. Components of learners’ conceptual ecology play a significant role in this evaluation process. Therefore, a learner’s awareness of the components of his/her conceptual ecology is important for comparing the status of competing conceptions. It is obvious that learners’ awareness of ideas and elements of their conceptual ecology, monitoring the consistency of existing and new ideas, and understanding of the new idea, and reflection on the status of competing ideas are inherent in the conceptual change process. Therefore, in classroom settings instruction should help students become aware of their existing conceptions and components of conceptual ecologies; monitor the understanding of the newly presented conception and the consistency between existing and new ideas; and evaluate the existing and new conceptions to explain the natural phenomena.

The Revisionist Conceptual Change Model

Although the theoretical framework of the CCM presented above has guided a great number of research and instructional practices for many years, it has also become subject to criticism even by the researcher who developed the initial model. One line of criticism focuses on the initial model’s rational approach to students’ learning. West and Pines (1983) claimed that learning in the CCM is not a “rational process” but there are also “nonrational components” of conceptual change. They suggested “nonrational processes are as much a part of what conceptual change is as are the rational parts” (p. 39). Similarly, Pintrich, Marx, and Boyle (1993) described the initial CCM as “cold” and “isolated.” They pointed out that the initial model put overemphasis on the rationality and neglects the role of motivational beliefs and classroom contextual factors in the process
of conceptual development. They proposed general motivational constructs, such as goals, values, self-efficacy beliefs, and control beliefs, to be potential mediators of conceptual change.

In response to the criticism that the conceptual change model is too rationalistic, two of the researchers who proposed the initial CCM presented a critique of the initial model and acknowledge the role of affective and social factors in conceptual change (Strike & Posner, 1992). They proposed that:

A wider range of factors need be taken into account in attempting to describe a learner’s conceptual ecology. Motives and goals and institutional and social sources of them need to be considered. The idea of conceptual ecology thus needs to be larger than the epistemological factors suggested by the history and philosophy of science. (p. 162)

In addition to the affective and social issues, their revisionist CCM is concerned also with the nature of a learner’s alternative ideas. Strike and Posner maintained that the initial CCM assumes that learners have symbolically represented paradigm-like alternative ideas before instructions. However, they argued that alternative ideas may not be formed prior to the instruction or need not be symbolically represented, but rather they may be generated as a consequence of the instruction by the pieces of the conceptual ecology. Therefore, creating dissatisfaction with the existing conception may not result in conceptual change if students do not have well-articulated paradigm-like alternative ideas. The instruction should not only focus on students’ existing conceptions, but also on the pieces of the conceptual ecology that generate alternative ideas.

Strike and Posner also maintained that the initial CCM views conceptions or alternative ideas as “cognitive objects” that are acted on by the pieces of conceptual
ecology but are not part of it. According to them, this assumption ignores the influence of current conceptions on new perceptions and new ideas. Our current conceptions influence how we perceive the world. They claimed that alternative ideas should also be considered as a piece in the conceptual ecology. Strike and Posner emphasized the interdependence and interconnectedness of past experiences, epistemological views of science, competing conceptions, analogies, and metaphors. They argued for a developmental and interactionist view of conceptual ecology and concluded that the CCM must “be more dynamic and developmental, emphasizing the shifting patterns of mutual influence between the various components of an evolving conceptual ecology” (p.163).

Other Theoretical Perspectives on Conceptual Change

The strength of CCM to explain how learners might change their existing conceptions has been acknowledged by several researchers in science education (Sinatra & Pintrich, 2003; Vosniadou, 1999). However, the nature of the learner’s conceptual knowledge and the nature of the change process are not explicitly addressed in this model. By the mid-1990s, several researchers began to take a closer look at the change process. Many researchers from cognitive psychology proposed different theoretical frameworks to explain the nature of the change in learners’ existing cognitive structure. These theoretical approaches described the change in learners’ ideas by focusing mainly on the nature of learners’ preconceptions and the nature of learners’ resistance against changing conceptions (Schnotz, Vosniadou, & Carretero, 1999). These perspectives on conceptual change mainly differ in terms of the researchers’ assumptions regarding the nature of human cognition (individualistic or situated cognition) and the general nature of
conceptions (coherent, theory-like, or fragmented). In the next section, a review of the different perspectives on the nature of learner’s conceptual structure and associated theoretical accounts on conceptual change is presented.

Knowledge in Pieces

With regard to the nature of learners’ conceptual knowledge, diSessa (1993) claimed that learners’ intuitive conceptions acquired from everyday experiences of the physical world do not possess a coherent structure, but rather they are isolated, fragmented “knowledge in pieces.” These knowledge pieces are primitive schemata constructed as a result of “superficial interpretation of the physical reality” (p. 112). Although these fragmented knowledge pieces called “p-prims” (phenomenological primitives) play important roles in explaining physical phenomena, they do not themselves need any explanations. For example, people do not try to explain the scientific principles for why a book can rest on a table or why a billiard ball strikes another. diSessa maintained that “not even physicists have time to reduce complex events to basic principles” (p. 107). Although these phenomenological events do not contain laws, they are known to take place without any need for justification at their occurrence. For instance, everyone knows that a book can rest on a table without considering the underlying scientific principle.

P-prims can describe small set of situations but they do not constitute a coherent and systematic theory. According to diSessa, p-prims are primitive in two ways: (a) P-prims are “self-explanatory” and they can be used without making any justification; (b) they are “atomic” and “isolated” elements of cognitive mechanisms. P-prims explain
other phenomena by “being cued to an active state on the basis of perceived configurations, which are themselves previously activated” (p. 112). Although they are not explained within the knowledge system, p-prims may act as intuitive physical laws while explaining a physical phenomenon. Even though p-prims may serve as a few core theoretical ideas that defer to much more complex knowledge structures for experts, they are nothing more than a superficial phenomenology that intuitively act as “heuristic cues” for naïve sense thinking.

In that sense, conceptual change occurs when there is a change in the functions of p-prims from relatively isolated, self-explanatory entities to the pieces of a larger system. In other words, conceptual change takes place when the collection of p-prims can provide an internally coherent and systematic explanation for the complex conceptual structure. In order for learners to construct internally coherent system of explanations, they need to be aware their superficial abstractions of their everyday experiences and monitor the inconsistencies in their use of p-prims in different contexts.

*Concepts as Coherent Mental Models*

Vosniadou (1994) presented a different view about the nature of learners’ conceptual knowledge. Her theoretical framework suggests that learners’ alternative ideas do not result from the incoherent and inconsistent knowledge pieces, but they result from learners’ attempts to create coherent mental models. According to Vosniadou, concepts are embedded in larger theoretical structures that constrain them. She distinguished between naive framework theories and specific theories. Framework theories consist of “entrenched” epistemological and ontological presuppositions, which are deeply rooted in
and constantly confirmed from daily life experiences. “Entrenched” presuppositions are built in early infancy and are usually not available to conscious awareness. Specific theories involve interrelated propositions or beliefs that explain the properties and behaviors of physical phenomena. They are domain-specific assumptions that are constrained by framework theories. Vosniadou described specific theory as “second-order constraints that emerge out of the structure of the acquired knowledge itself” (p. 48).

Vosniadou claimed that during cognitive functioning, individuals generate or retrieve mental models to provide causal explanations of physical phenomena or to predict the state of affairs in the physical world. Mental models are dynamic and generative representations that can constrain the knowledge acquisition process in a similar way as beliefs and presuppositions. Mental models are usually created during problem solving. However, if the individual finds the mental model useful, s/he can store it in long-term memory and retrieve it when needed.

The ways in which framework theories constrain further knowledge acquisition can be seen in Vosniadou’s explanation of children’s mental models about the shape of Earth. Younger children, in her study, constructed mental models in which Earth is shaped like a flat rectangle or like a disc that is supported by ground underneath and is surrounded by sky above its flat top. Vosniadou referred these models as “initial” because they are based on everyday experience rather than on the scientific model of the spherical Earth. Older children, in her study, generated models that combine initial models with the scientific model of the spherical Earth. For example, many of the older children in their study imagined Earth as a hollow sphere, which is similar to a goldfish bowl with a flat bottom where people are assumed to live. Vosniadou concluded that the initial concept of
Earth influenced the way children interpret the new information they receive about the spherical shape of Earth. Vosniadou (1999) maintained that children generate “synthetic” mental models in order to reconcile the information about the spherical shape of Earth “with their presuppositions and beliefs that the ground is flat, that the space is organized in terms of the directions of up and down and that unsupported physical objects fall in a downward direction” (p. 7). In other words, children reconcile their framework presuppositions inferred from everyday experiences with the new information. In this case, children do not have difficulty in understanding the new information correctly, but they attempt to construct a mental model constrained by inappropriate presuppositions and beliefs.

According to Vosniadou (1994), conceptual change involves gradual changes in learner’s “synthetic” mental models with scientifically accepted mental models. Revision of the “synthetic” models (in other words, alternative ideas) requires a change in the naïve framework theory and in specific theories. This process is very difficult, especially when the framework presuppositions are entrenched because in that case, conceptual change requires a revision in epistemological and ontological presuppositions that are consistently confirmed by everyday experiences. Vosniadou and Ioannides (1998) argued that:

Students (both children and adults) are not aware of the hypothetical nature of the presuppositions and beliefs that constrain their learning. They take them to be facts about the way physical world operates rather than propositions in a hypothetical explanatory framework subject to verification. … Lack of metaconceptual awareness of this sort prevents children from questioning their prior knowledge and encourages the assimilation of new information to existing conceptual structures. This type of assimilatory activity seems to form the basis for the creation of synthetic models and misconceptions and lies at the root of the
surface inconsistency so commonly observed in students’ reasoning. (pp. 1222-1225)

Vosniadou and Ioannides (1998) pointed out the need to design instructional interventions to increase students’ “metaconceptual awareness” of their “implicit representations, as well as of the beliefs and presuppositions that constrain them” (pp. 1223-1224).

**Ontological Categories**

A further theoretical framework developed by Chi, Slotta, and Leeuw (1994) is based on the assumption that there are categorical differences between science concepts. Chi et al. proposed that entities in the world belong to three different ontological categories: matter (or things), processes, and mental states. There are also several subcategories embedded within each major category. For example, the processes category involves “procedure,” “event” and “constraint–based interaction” subcategories. Matter category is divided into “natural kind” and “artifacts,” whereas the mental states category is divided into “emotional” and “intentional.” One category differs from the others in terms of some ontological attributes. Chi et al. defined ontological attribute as “a property that an entity *may potentially possess* as a consequence of belonging to that ontological category” (p. 29, italics in original). For instance, entities within the matter category (such as sand, paint, and human beings) have ontological attributes as “being containable,” “storable,” “having volume and mass,” and “being colored.” On the other hands, processes own their own set of ontological attributes, such as “occurring over time,” “resulting in,” and so forth.
According to Chi et al. (1994), many of the science concepts belong to the “constraint-based interaction” category that is subsumed under the main category of processes. Chi et al. identified ontological attributes of this category as “no beginning and end, no progression, acausal, uniform in magnitude, simultaneous, static, and on-going” (p. 32). Force, electrical current, heat, and light are some examples of the physical concepts that belong to this category. Chi et al. argued that students have difficulty in learning science concepts due to “the existence of mismatch or incompatibility between categorical representation that students bring to an individual context, and the ontological category to which the science concepts truly belongs” (p. 34). According to this approach, alternative ideas arise when the learner assigns a concept to a wrong ontological category. For example, students frequently assume that the force concept is under the category of matter rather than the subcategory of constraint-based interaction. As a result, they consider force as a kind of substance that an object possesses and consumes. Another example of students’ misclassification is electricity concept. In many introductory textbooks, flowing water is used as an analogy to explain the electrical current. This analogy leads students to perceive the electrical current concept under the matter category, more specifically liquid subcategory. This category has the ontological attributes, such as “has volume,” “occupies space,” and other properties of matter category. Classification of electrical current as liquid leads students to have alternative ideas, such as “it can be stored in the battery” or “it can be used up” (p. 34). When students who categorize force or electrical current as matter are presented with new information about the concept of force or electrical current, the new information will be
assimilated into the matter category as well. Thus, students cannot understand the concept completely if the ontological category of the concept is not changed.

According to this theoretical framework, conceptual change involves the reallocation of a concept to the appropriate category within the existing structure. Chi and Roscoe (2002) pointed out the importance of students’ awareness of their conceptions and the category they assign those conceptions. They claimed that students’ difficulty to assign a concept to another ontological category comes “from mainly the fact that students may lack awareness of when they need to shift, and may lack an alternative category to shift into” (p. 18). Students may not be aware of their alternative ideas if the “miscategorized concept” can generate predictable responses to questions and systematic explanations of the phenomena.

Profile Change

Mortimer (1995) constructed another theoretical framework that not only considers ontological distinctions, but also takes into account the hierarchical and context-dependent nature of epistemological and ontological distinctions among different usage of a single concept. Mortimer maintained that a new concept does not necessarily replace alternative ideas; instead, individuals (even experts) keep using their alternative ideas in their daily life. His model is based on the notion of “conceptual profile” consisting of hierarchical zones, each of which is ontologically and epistemologically different from the others. As one moves from the zones of the conceptual profile, the conceptual features of each zone change in terms of some ontological and epistemological characteristics.
The conceptual profile of one concept differs from one learner to another, since the zones are strongly influenced by different personal experiences and different cultural roots. Based on the nature of concepts, there might be several zones of conceptual profile. For example, for the concept of matter, he proposes four different zones: (1) realist view of matter (continuous; no reference to particles; external appearances and sensible features), (2) a substantialist (empirical) view of matter (matter as constituted by particles; analogy between the behavior of particles and that of the substances), (3) classical (rational) atomistic view (the atom as a system of sub-particles; conservation of matter; transition from external features to internal features; interaction between particles in each physical state of matter), and (4) a quantum (rational modern) view of matter (the atom as a system of quantum objects described by mathematical models). Each successive zone (realist, empiricist, rational classic, and rational modern) within the conceptual profile has more explanatory power than lower zone. In their everyday life, even the scientists use matter as something continuous but when they deal with a problematic situation they shift to a scientific profile, such as a developed atomistic view or quantum view. Mortimer distinguished experts from novice students in that the experts are conscious of their conceptual profile and can use each notion in their profile in the appropriate contexts.

Mortimer’s theoretical framework suggests that learning science is not viewed as a conceptual change in which the new conceptions replace the previous conceptions, but rather it involves changing the conceptual profile and acquiring the capability to distinguish the different zones of the profile. Then, the aim of teaching should to help
students become conscious of their conceptual profile and decide where each concept is applicable.

*Contextualization of Conceptions*

Researchers from a different theoretical orientation argue that conceptual change should be extended to include contextual and situational factors. According to this perspective, conceptual change is achieved by enhancing individuals’ ability to differentiate between contexts. Linder (1993) referred to this process as “conceptual appreciation” to emphasize how lack of appreciation for the context in which science concepts are embedded inhibits meaningful learning of science. He claimed that concepts are not “appropriate, legitimate, correct, or otherwise” (p. 295) without contexts. He provided several examples from physics to emphasize the necessity of conceptual appreciation in meaningful understanding of science. Appropriateness of concept requires a context. For instance, the conceptualization of light as a particle or wave depends upon the context. Similarly, appropriateness of electric current also depends on the context. Students usually conceptualize electric current as a flow of electrons. This view is correct if we are looking at special cases, such as a metal or a vacuum tube. In liquid and gaseous conductors, on the other hand, electric current is conceptualized as the flow of positive and negative charges. Linder argued that science educators should put less emphasis on the efforts to change the existing conceptions and more emphasis on the efforts to enhance students’ capability to appreciate functional appropriateness of science conceptions in particular context.
In response to diSessa’s (1993) article about p-prims, Ueno (1993) argued that students’ difficulties in learning science concepts from the viewpoint of situated cognition. Ueno agreed with diSessa in that naïve theory is an ad hoc explanation. However, he claimed that naïve theory does not exist in individuals’ minds in a vacuum, but rather it is socially formed and embedded in a specific “language game” in a specific community. Robustness of naïve theory is not a result of individual’s cognitive system, but rather it comes from “a specific social maintenance system and the given stable natural environment” (p. 244). According to Ueno, representation of a naïve theory about a physics concept resides in an interactive system among individuals, the community, and the stable natural environment, such as gravity and static state of ground. He maintained that in everyday situations, gravity and the static state of the environment are tacitly considered as natural. Implicit presuppositions not only are in individuals’ minds, but are socially shared in everyday discourse.

In order to illustrate how the static state of ground is socially shared, Ueno gave examples of everyday and Newtonian discourse. In everyday discourse, individuals do not note explicitly the frame of reference for their observation in their statements, such as “The speed of this car is 50 miles per hour.” In this example, the static ground is tacitly considered as natural. In a Newtonian discourse, on the other hand, the reference of the observation is explicitly noted in individuals’ statements, such as “What is your frame of reference for telling the velocity of that car? Is it the Earth, the solar system, or the galactic system?” (p. 240).

Ueno maintained that everyday discourse and Newtonian discourse differ in terms “metacontext.” He claimed that if students do not know the metacontext of Newtonian
Physics, falsification of their predictions cannot produce conceptual change. Without clarifying metacontext, students’ interpretation tends to be very local even after they can correctly predict a physical phenomenon. In order to learn Newtonian physics, students need to clarify the difference between the metacontext of everyday discourse and that of Newtonian physics. According to Ueno’s view, conceptual change is not regarded as the transition from one conceptual structure to another, but rather a process involving “expansive recontextualization” (p. 247).

Summary of the Theoretical Perspectives on Conceptual Change

Different theoretical approaches have been proposed to explain how students learn science concepts. These theoretical frameworks differ in their assumptions about the nature of knowledge acquisition. Although some of the researchers (including Posner et al. (1982), diSessa (1993), Vosniadou (1994), and Chi et al. (1994)) considered knowledge acquisition as an event that occurs in the mind of individual, others (such as Linder (1993) and Ueno (1993)) emphasized the situated nature of knowledge acquisition and conceived it as a socially shared event between cognitive agents.

These theoretical orientations mainly underline the role of learners’ epistemological and ontological presuppositions, learners’ interpretations of “self-explanatory” and isolated everyday experiences, and the context in the development of alternative ideas. Although there are differences in the assumptions of the researcher in terms of the nature of students’ conceptions, they do not view conceptual change as a simple replacement of the previous conceptions with the new ones. Rather, conceptual change is a complicated and multifaceted process in the sense that it not only involves a
basic replacement of the existing conception with the new conception but also a major multifaceted restructuring of the mental structure and its underlying elements. Duit (1999) claimed “conceptual change theory as used in science education is no longer the pure initial theory” (p. 266). According to the theoretical accounts that emerged in the mid-1990s, conceptual change involves integrating the phenomenological experiences appropriately into a coherent and complex knowledge structure, changing epistemological and ontological presuppositions, interpretations of everyday life experiences, and differentiating and recognizing contexts associated with specific use of a conception.

These theoretical perspectives suggest that designing instructional activities that involve confronting students with situations that show that their conceptions are wrong may not be enough to bring about a change in students’ conceptual structure. They mainly highlighted the importance that metacognitive awareness of existing conceptual structure, monitoring and evaluating thinking play when learning a new conception. Table 2.1 summarizes theoretical perspectives on conceptual change along with their instructional implications that emerged from their conceptualization of the nature of students’ alternative ideas and conceptual change process.

No matter which theoretical framework is used to explain the change in students’ conceptions, the instructional implications emerging from these different frameworks suggest that students should be helped to become aware of their conceptions and the elements of their conceptual ecology, the context in which a conception is used, and they should monitor the consistency of ideas and evaluate competing ideas by reflecting on the status of them. Awareness, monitoring and evaluation are the key components of
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<th>Theoretical Perspective</th>
<th>Views on Conceptual Change</th>
<th>Instructional Implications</th>
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<td>Conceptual Change Model (Posner et al., 1982)</td>
<td>A change from existing conception to a new conception after the conditions intelligibility, plausibility, fruitfulness and dissatisfaction are met within the context of learner’s conceptual ecology.</td>
<td>Helping students become aware of their existing conceptions and elements of conceptual ecology, monitor the understanding of new conception and consistency between existing and new conception, evaluating ideas by making comments on the believability and usefulness of ideas.</td>
</tr>
<tr>
<td>Status Change (Hewson, 1981)</td>
<td>Lowering the status of the existing conception while raising the status of the new conception.</td>
<td>Helping students monitor and evaluate the status of existing and new conceptions.</td>
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<td>Knowledge in Pieces (diSessa, 1993)</td>
<td>A change in the functions of p-prims from relatively isolated, self-explanatory entities to the pieces of internally coherent complex system.</td>
<td>Helping students become aware of their fragmented and isolated pieces of knowledge, monitor their use of knowledge pieces in different contexts and recognize the inconsistencies among them.</td>
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<tr>
<td>Concepts as Mental Models (Vosniadou, 1994, 2003)</td>
<td>A gradual change in the coherent “synthetic” mental structures constrained by their naïve epistemological and ontological presuppositions.</td>
<td>Helping students become aware of their mental models and epistemological and ontological presuppositions that constrain their mental models; and differentiate between their own epistemological and ontological presuppositions and that of scientific views.</td>
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<tr>
<td>Ontological Categories (Chi et al., 1994)</td>
<td>Reassignment of a conception in a scientifically appropriate ontological category.</td>
<td>Helping students become aware of their ontological presuppositions and recognize and differentiate the ontological characteristics behind their own ideas and scientific views.</td>
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Table 2.1: Instructional implications of different perspectives on conceptual change.

(continued)
Table 2.1 continued

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<th>Theoretical Perspective</th>
<th>Views on Conceptual Change</th>
<th>Instructional Implications</th>
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<td>Profile Change (Mortimer, 1995)</td>
<td>Changing the conceptual profile and acquiring the capability to distinguish the different zones of the profile.</td>
<td>Fostering students’ consciousness about the zones of their profile, the associated epistemological and ontological commitments, and the functional differences of ideas among different contexts.</td>
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<tr>
<td>Contextualization of Conceptions (Linder, 1993; Ueno, 1993)</td>
<td>Distinguishing functional appropriateness of conceptions in particular contexts.</td>
<td>Helping students monitor the function of a concept in different contexts.</td>
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</table>

metacognition. In this study, processes including awareness, monitoring and evaluation that are acting on and related to one’s conceptions are subsumed within the term “metaconceptual processes.” Before presenting more detailed information about the nature of metaconceptual processes, the term metacognition and the characteristics of the underlying knowledge and processes under the heading of metacognition are explained in the next section.

Metacognition

Since its first use by Flavell more than a quarter century ago, the prefix meta has been used to qualify a wide range of constructs in many areas, such as metalinguistics, metareading, metacomprension, metaperception, metamemory, and metacognition. Originally this Greek prefix gave a “transcendent character” to the term it qualified.
Recently, however, the words beginning with “meta” indicate “a view of things from
outside, a more abstract level and a more mature understanding” (McNeil, 1992, p. 55).

Among the constructs qualified by the prefix meta, metacognition is the one that
has the broadest meaning and that has gained a great deal of attention. Metacognition has
become one of the most prominent constructs in cognitive and educational psychology.
Since its use by Flavell, various forms of behaviors, skills, and knowledge have been
subsumed under the heading of metacognition. Many researchers have used a variety of
theoretical frameworks and methodologies to describe and study this construct. Despite
its widespread use and pronounced impact in many areas of psychological and
educational research, metacognition has been described as a “fuzzy concept” (Flavell,
separate historical roots, to the difficulties in distinguishing metacognitive processes from
cognitive processes, and to the use of a single term to describe a broader range of
processes skills and types of knowledge.

Metacognition is most broadly defined as “one’s knowledge and control of own
cognitive system” (Brown, 1987, p. 66). The term metacognition is also simply defined
as “thinking about one’s own thinking” (Rickey & Stacy, 2000), “knowledge about
knowledge” or “reflections about actions” (Weinert, 1987). Hennessey (2003) identified
metacognition as one’s “inner awareness” about one’s learning process, what one knows
(content knowledge), or one’s current cognitive state. Kuhn, Amsel, and O’Loughlin
(1988) described metacognition as “thinking explicitly about a theory one holds (rather
than only thinking with it)” (p.7). Baird (1990, p. 184) defined metacognition as
“knowledge, awareness and control of one’s own learning.” These definitions suggest
that metacognition is a complex and multifaceted construct that covers a broad range of mental functioning.

**Taxonomies of Metacognition**

Metacognition is a multidimensional construct involving various kinds of knowledge and processes. This feature of this construct has led various researchers and theorists to propose different taxonomies to clarify and classify the knowledge and processes under the heading of metacognition.

**Flavell’s Taxonomy of Metacognition**

Among various taxonomies, Flavell’s (1979) taxonomy has helped many researchers operationalize and investigate the notion of metacognition. Flavell’s (1976) definition of metacognition involves knowledge about the cognitive system and its contents and the effective regulation and control of that system:

Metacognition refers to one’s knowledge concerning one’s own cognitive processes and products or anything related to them, e.g., the learning-relevant properties of information or data. … Metacognition refers, among other things, to the active monitoring and consequent regulation and orchestration of these processes in relation to cognitive objects or data on which they bear, usually in the service of some concrete goal or objective. (Flavell, 1976, p. 232)

Flavell (1979) proposed a model of metacognition and cognitive monitoring. According to this model, cognitive monitoring occurs through “the actions and interactions among four classes of phenomena: “(a) metacognitive knowledge, (b) metacognitive experiences, (c) goals (or tasks), and (d) actions (or strategies)” (p. 906).

Metacognitive knowledge refers to one's acquired knowledge that "has to do with people as cognitive creatures and with their diverse cognitive tasks, goals, actions, and
experiences” (Flavell, 1979, p. 906). This knowledge is both “statable” in that it can be assessed through verbal reports, and it is “stable” in that once the individuals possesses information about themselves as learners and about cognition in general, they continue to have this information stored in their memory (Brown, 1987; Campione, 1987). According to Flavell (1979), metacognitive knowledge is not qualitatively different from other kinds of knowledge, but rather it differs from other kinds in its “content and function” (p. 906). Metacognitive knowledge is simply a portion of the total knowledge base that is related to cognition (Flavell, 1987). Flavell (1979) made a distinction among different types of metacognitive knowledge into person, task, and strategy variables.

Person variable includes one’s knowledge about himself/herself or others as cognitive processors. In other words, it involves one’s knowledge about oneself and the others as learners, about what factors influence her/his mental processing and about cognitive capacities. Flavell (1979) further divided person variable into three categories: intraindividual, interindividual, and universal knowledge. Statements such as “I can learn things better by reading than listening,” “My memory span is limited,” and “I am good at dealing with verbal kinds of material but not good at spatial tasks” can be subsumed under the intraindividual person variable. An individual can also form knowledge about how her/his cognitive skills compare with those of others. In this case, this knowledge is referred as interindividual person variable. For example, an individual’s knowing that s/he is brighter than her/his parents can be categorized as interindividual person variable. Universal person variable refers to one’s knowledge about cognition in a general sense. For example, one’s statements such as “Short-term memory is fallible and has limited capacity” or “One has to pay close attention to something in order to learn it” show that
s/he has a universal knowledge about memory and learning. Students may also possess stored knowledge about concept learning.

Research studies examining what learners know about their own cognition have shown that children are less informed about the stable characteristics of their own learning (Flavell & Wellman, 1977). According to Brown (1987), children do not possess stable and statable knowledge about their cognitive processes, due to their lack of relevant experiences in most learning environments. One of the aims of this study is to promote students’ knowledge about their concept learning through providing them with opportunities to reflect on general characteristics of conceptual learning and their own learning of science.

Task variable refers to one’s knowledge about a task itself, its demands and relative difficulty. In other words, task variable is an acquired knowledge that different kinds of tasks place different kinds of demands on individuals (Flavell, 1979; 1987). For example, one’s knowledge that it is easier to recall the main events of the story than to recite the story word to word or familiar-topic task is easier to understand than unfamiliar tasks can be considered as task variable. An individual’s recognition of a certain type of a task and its demands indicates the existence of metacognitive knowledge of task variable.

Strategy variable involves one’s knowledge about different types of cognitive and metacognitive strategies that can be used to achieve various goals. Flavell (1979, 1987) made a distinction between cognitive and metacognitive strategies. Depending on the goal of the learner, a strategy can be referred as either cognitive strategy or metacognitive strategy. Flavell (1979) described the functional differences between cognitive and metacognitive strategies by stating that “cognitive strategies are invoked to make
cognitive progress, metacognitive strategies to monitor it” (p. 909, italics in original). Cognitive strategies are used to help an individual achieve a particular goal (e.g., rereading the text for understanding) while metacognitive strategies are used assess progress towards goals (e.g., asking oneself questions to evaluate one's understanding of that text). This study did not aim to promote students’ metacognitive knowledge about tasks and strategies.

According to Flavell (1979), metacognitive knowledge is not qualitatively different from other kinds of knowledge, but rather differs from other kinds in its “content and function” (p. 906). Metacognitive knowledge is simply a portion of the total knowledge base that is related to cognition (Flavell, 1987). In other words, it is similar in many ways to other kinds of knowledge in the long-term memory that individuals can have about any topic, such as mathematics, animals, or furniture (Pintrich, Wolters, & Baxter, 2000). Like other kinds of knowledge, it is acquired through years of experiences in the domain of cognitive activity and it can be either declarative or procedural (Flavell, 1985).

The other key component of Flavell’s (1979) taxonomy is metacognitive experiences. Flavell (1979) defined metacognitive experiences as “any conscious cognitive and affective experiences that accompany and pertain to any intellectual enterprise” (p. 906). Metacognitive experiences are mostly related to one’s progress towards the goal of completing a task or cognitive activity successfully and they can arise before, during, and after a cognitive activity (Garner, 1987). Flavell (1987) described metacognitive experience:
One is having a metacognitive experience whenever one has the feeling that something is hard to perceive; comprehend, remember, or solve; if there is the feeling that one is far from the cognitive goal; if the feeling exists that one is, in fact, just about to reach the cognitive goal; or if one has the sense that the material is getting easier or more difficult than it was a moment ago. (p. 24) Unlike metacognitive knowledge, metacognitive experiences are presumed to be relatively unstable, rarely statable, and relatively independent of age (Brown, 1987). For example, a feeling of discomfort and puzzlement in response to incomplete directions implies the existence of metacognitive experience. Similarly, a student’s momentary sense that s/he does not understand something explained by the teacher can be categorized as a metacognitive experience. Garner (1987) described metacognitive experiences as awarenesses, realizations, and “ahas” (p. 19).

In summary, as Flavell’s description of the components of metacognition suggests, metacognitive knowledge refers to one’s stored knowledge about one’s own cognitive capabilities, one’s own learning, or universal characteristics of learning. In contrast, metacognitive experience involves control and regulatory processes, such as an active monitoring of one’s cognitive processes and awareness of one’s own thinking.

*An Alternative Definition of Metacognitive Knowledge*

Chi (1987) provided an alternative view to explain metacognitive knowledge. According to Chi, the term meta can be used in two different ways: “as a reference to cognition” and “as a reference to secondary-order knowledge” (p. 249). If it is used as a reference to cognition, one could substitute the word meta by the words cognition or knowledge. Thus, the word metaknowledge means cognition about knowledge. For example, one’s knowledge about his or her learning styles can be characterized as...
metaknowledge. On the other hand, if meta is used as a reference to second-order
knowledge, a function or a procedure is used on existing declarative knowledge.

In her taxonomy of metacognitive knowledge (which she called metaknowledge),
Chi (1987) categorized metaknowledge in terms of the differences in representation
between the knowledge states. Chi identified three types of metaknowledge: meta-
declarative knowledge, meta-procedural knowledge, and meta-strategies.

Chi proposed that there are two kinds of meta-declarative knowledge. The first
type of meta-declarative knowledge is one’s pre-stored factual knowledge about
cognition. It is stored in memory like other kinds of knowledge and acquired through
experience. The difference between stored meta-declarative knowledge and other kinds
of declarative knowledge lies in its content. For example, if one has existing knowledge
about how much s/he can generally recall, or if s/he has knowledge about what kinds of
tasks are the most difficult, or if s/he has knowledge that s/he is better at listening than
reading, s/he has meta-declarative knowledge that is encoded as a result of past
experiences and that can be retrieved from long-term memory like other factual
knowledge in other domains. In that sense, this kind of meta-declarative knowledge is
similar to Flavell’s conceptualization of person and task variable. In the case of concept
learning, for example, a learner may have knowledge that s/he may hold conceptions that
are different from scientists. Similarly, a learner may possess knowledge that his or her
alternative ideas may not be applicable to every situation.

For the second kind of meta-declarative knowledge, Chi used the term meta as a
function or second-order operation. If the necessary knowledge about cognition is not
stored or known, meta-declarative knowledge would be “a procedure that takes as input
declarative knowledge, and the action would be an evaluation or some kind of assessment” (p. 262). For example, if an individual is asked if s/he knows about a force concept, s/he needs to search or activate relevant nodes in his/her semantic network and answer when the available structure is activated. However, if s/he is asked how much s/he knows about a force concept and this knowledge is not stored, it is required to activate relevant nodes, and also some evaluation and quantification of the activated portion of the semantic network is needed. In other words, if the necessary knowledge about the cognition does not exist in the memory, “a function or a procedure is used when an evaluation or any other form of action is taken on existing declarative knowledge” (p. 250).

Similar to the meta-declarative knowledge, *meta-strategies* can be defined in two ways. Meta-strategies can be either represented as pre-stored declarative knowledge or they can be viewed as second-order operations. For example, one’s knowledge that her/his rehearsal production is efficient is represented like factual knowledge in other domains. This kind of knowledge is encoded through experiences and can be retrieved if it is needed. In the case of second-order operations, however, meta-strategies “take entire strategy production as inputs and output some evaluation of the production” (p. 251). For instance, if one is asked whether s/he can remember better than her/his friends and if the answer to this questions is not pre-stored, her/his response requires an evaluation of what kind of strategies s/he knows and how effective those strategies facilitate remembering. In that sense, meta-strategy is “a rule that takes as input another rule, and output some output or action” (p. 252). Representation of meta-procedural knowledge is very similar to the representation of meta-strategies. The difference between two lies in the domain-
specificity of meta-procedural knowledge. Thus, meta-procedural knowledge involves the rules that evaluate other domain-specific rules.

**Other Taxonomies of Metacognition**

In addition to the attempts to clarify metacognitive knowledge, there have been other approaches to compartmentalize the components of metacognition. Schraw and Moshman (1995) proposed a taxonomy of metacognition that is similar to Flavell’s (1979) taxonomy in that it distinguishes between two components of metacognition: (a) knowledge of cognition and (b) regulation of cognition. They defined knowledge of cognition as what one knows about her/his own cognition or about cognition in general. In that sense, their definition of knowledge of cognition overlaps with Flavell’s (1979) definition of metacognitive knowledge. According to Schraw and Moshman (1995), individuals hold metacognitive theories about cognition. Metacognitive theories are “theories of mind that focus on cognitive aspects of the mind” (p. 357). These theories involve beliefs and postulates that allow individuals to explain and predict their own cognition, cognition of others, and cognition in general. The extent to which an individual is aware of his/her metacognitive theories varies from person to person. In other words, an individual’s theories about cognition may be either explicit or tacit. Although individuals may not report having these theories, these implicit theories may systematically influence their behavior. Schraw and Moshman (1995) argued that metacognitive theories change gradually over time, given the personal experience and self-reflection. Students’ knowledge about their own concept learning and general characteristics of learning can be classified within this category.
Another component of Schraw and Moshman’s (1995) taxonomy is regulation of cognition. Regulation of cognition refers to “metacognitive activities that help control one’s thinking or learning” (p. 354). There are three essential metacognitive skills under this category: planning, monitoring, and evaluation. Planning includes “the selection of appropriate strategies and allocation of resources that affect performance” (p. 354). For example, deciding how much time to give to a task, how to start, what resources to gather, what order to follow, what to skim and what to give intense attention can be considered as planning activities. Monitoring is the “on-line awareness of comprehension and task performance” (p. 355). For example, one’s self-questioning, such as “How am I doing?” “Am I reading too fast?” and “Do I understand what I am listening to?” is an indication of experiencing monitoring. Evaluation involves making judgments about the products and regulatory processes of thinking and learning. A typical example of this metacognitive activity can be one’s evaluating a use of strategy to achieve the goal by asking “Do I need to use another strategy for the next time?” One of the conditions that needs to be satisfied for the change in students’ conceptions proposed in the Conceptual Change Model (Posner et al., 1982) is the intelligibility of the new conception. Thinking about whether the new conception is intelligible requires the learner to monitor the comprehension of the new conception. Moreover, when a learner compares the status of the competing conceptions to explain the natural phenomenon, s/he makes judgment about the existing and new conceptions. Therefore, evaluating the plausibility and usefulness of conceptions can be identified as a regulatory activity.

Like Flavell (1979) and Schraw and Moshman (1995), Hertzog and Dixon (1996) differentiated the knowledge component of metacognition from online metacognitive
processes. They distinguished two types of metacognition: “stored” and “concurrent.” While stored metacognition involves representations or information held in permanent, long-term memory either in the form of knowledge or beliefs, concurrent metacognition produces the information generated by the act of cognising. Concurrent metacognitive processes not only are responsible for monitoring the current status of the cognitive system (Nelson & Narens 1990), but they are also associated with conscious awareness of the content and processes of cognising (Cavanaugh 1989).

Pintrich, Wolters, and Baxter (2000) proposed a different taxonomy in which they divided metacognition into three components rather than into metacognitive knowledge and metacognitive regulation. The difference in their taxonomy and in the previously proposed taxonomies lies in their distinction between monitoring and regulation of cognition. Their taxonomy consists of three general components of metacognition: (a) metacognitive knowledge, (b) metacognitive judgments and monitoring, and (c) self-regulation and control of cognition. Pintrich et al. (2000) claimed that, although awareness indicates a conscious experience, metacognitive knowledge is labeled as metacognitive awareness in some models of metacognition. Therefore, they preferred to consider metacognitive awareness as an aspect of metacognitive judgment and monitoring. Self-regulation and control of cognition involve the types of activities “that individuals engage in to adapt and change their cognition or behavior” (p. 50).

Similar to Pintrich et al.’s (2000) taxonomy of metacognition, Gunstone and Mitchell (1998) differentiated three components: metacognitive knowledge, metacognitive awareness, and metacognitive control. They defined metacognitive knowledge as one’s “knowledge of the nature and processes of learning, of personal
learning characteristics, and of effective learning strategies and where to use these” (p. 136). They characterized metacognitive awareness as one’s “perceptions of the purpose of the current activity and of personal progress through the activity,” while they identified metacognitive control as “the nature of learner’s decisions and actions during the activity” (p. 136).

According to Georghiades (2004), the notions of consciousness and reflection are tightly related to metacognition. Von Wright (1992) differentiated two levels of reflection. At the lower level a learner is capable of reflecting “about many features of the world in the sense of considering and comparing them in her mind, and of reflecting upon her means of coping in familiar contexts.” In other words, at the lower level, the learner becomes conscious of his/her ideas about the word and compares and contrasts them in his/her mind. At the higher level, however, the learner reflects about himself/herself “as the intentional subject of her own actions” (Von Wright 1992; pp. 60–61). At this level learners reflect about their reasoning performance by reasoning how they reason. Hennessey (2003) characterized metacognition as an ”inner awareness” which is about “what one knows (content knowledge), one’s learning processes (knowledge construction), or one’s current cognitive state (awareness of mental constructs)” (p. 107).

**Summary of the Taxonomies of Metacognition**

The taxonomies above identify and classify a range of components of metacognition, suggesting that the term metacognition has been used to describe a wide range of knowledge and mental operations. Researchers’ use of inconsistent and
imprecise terminology to denote the same constructs under the heading of metacognition contributes to the definitional vagueness of the term. For example, although they referred to the static stored knowledge about cognition and learning, Flavell (1979) used person variable, Chi (1987) used meta-declarative knowledge, and Schraw and Moshman (1995) used declarative knowledge of cognition as the terms to label the same construct.

The taxonomies of metacognition mainly address three different key characteristics of metacognition: knowledge about cognition, awareness, and control and regulatory processes. Alexander, Schallert, and Hare (1991) defined knowledge as “an individual’s personal stock of information, skills, experiences, beliefs and memories” (p. 317). This definition suggests that knowledge is an acquired entity rather than a process. Therefore, having metacognitive knowledge implies that one has a stock of information about cognition, learning or factors that influence learning. Individuals acquire information about cognition as a result of their experiences. Schraw and Moshman (1995) maintained that this knowledge can be explicit or implicit. That is, individuals can use this knowledge consciously or they can systematically use this knowledge at subconscious level without being aware of it.

Chi’s (1987) definition of metaknowledge involves both knowledge as pre-stored information about cognition, and processes as second-order operations on existing declarative knowledge. The object of second-order operations need not necessarily be one’s stock of knowledge about cognition; rather second-order operations on existing declarative knowledge of any kind are considered as having metacognitive character within Chi’s theoretical framework of meta-knowledge. Therefore, thinking and reasoning about, quantifying and evaluating one’s existing declarative knowledge can be
subsumed under the heading of metacognitive processes. Similarly, Kuhn, Amsel, and O’Loughlin (1988) also described “thinking explicitly about a theory one holds (rather than only thinking with it)” (p.7) as a metacognitive process. While engaging in metacognitive processes that are acting on existing declarative knowledge individuals not only become aware of the particular declarative knowledge but they think and reason about, quantify, and make judgmental decisions about the stored declarative knowledge.

Pintrich et al. (2000) and Gunstone and Mitchell (1998) distinguished between metacognitive knowledge and metacognitive awareness. Metacognitive awareness is characterized by one’s consciousness of his/her cognitive state. Control and regulatory processes are key components of metacognition. Processes such as planning, monitoring and evaluation are control and regulatory processes that involve monitoring of ongoing activities and decisions that are directed at the modification or maintenance of cognitive behaviors or products of thinking. According to Hennessey (2003) metacognitive awareness not only is about one’s learning processes, but also “what one knows (content of knowledge)” (p. 107).

To sum up, taxonomies proposed to classify qualitatively distinct components of metacognition differentiated the following knowledge and processes: metacognitive knowledge (knowledge about cognition), awareness of one’s cognitive state, monitoring of on-going thinking processes, and regulatory (evaluation) processes involving decisions that are directed at keeping or changing current cognitive state or behaviors.
Researchers’ views of metacognition are varied and highly affected by the disciplinary area they study (Hacker, Dunlosky & Graesser, 1998). Various theoretical and empirical studies investigated the role of metacognition in memory performance, reading comprehension and problem solving (Campione, 1987). Due to the multidimensional character of metacognition, these studies focused on only particular knowledge and processes. For example, studies in the field of reading mainly focused on students’ skills to monitor text comprehension (Maki, 1998). Recently, many researchers in science education have acknowledged the role of metacognitive processes in facilitating or mediating change in students’ conceptions (Beeth, 1998; Ferrari & Elik, 2003; Gunstone & Mitchell, 1998; Hennessey, 1999, 2003; Hewson, Beeth, & Thorley, 1998; Vosniadou, 1994, 2003; Vosniadou & Ioannides, 1998; White & Gunstone, 1989). Collectively, they emphasized students’ consciousness of and reflection on their conceptions. Despite researchers’ acknowledgement of the intertwined nature of metacognitive processes and the change in learners’ conceptions, the nature and the mechanisms of the metacognitive knowledge and processes that are related and acting on learners’ conceptions have not been well clarified in the literature.

The term metacognition has been used as a blanket term that covers a wide range of knowledge and processes. Hennessey (1999, p. 6) characterized the multidimensional character of metacognitive processes by differentiating five different processes under the heading of metacognition: (a) an awareness of one’s own thinking; (b) an awareness of one’s content of conception; (c) an active monitoring one’s cognitive processes; (d) an attempt to regulate one’s cognitive processes in relationship to further learning; and (e)
an application of a set of heuristics as an effective device for helping people organize their methods of attack on problems in general. Among these processes that are subsumed under the heading of metacognition, Hennessey (2003) underlined the importance of “conscious and deliberate thoughts that have ideas as their object” in changing students’ conceptions (p. 107). Hennessey claimed that metacognitive processes such as “execution of learning strategies,” use of “heuristics” for solving problems or “regulation of behavior while performing a complex task” are skills that have “potential to lead to success on a given task.” On the other hand, these abilities “do not guarantee an awareness of one’s own thoughts or an ability to contemplate the rational arguments used to support one’s knowledge claims,” which are critical processes in changing students’ conceptions (p. 107). In other words, facilitating learners’ engagement in metacognitive processes, such as use of effective learning strategies or problem-solving heuristics, may not be enough to bring about a major restructuring in learners’ conceptual structure, although they may lead to successful task performance. Metacognitive knowledge and processes that are intertwined with major restructuring in learners’ conceptual systems have not been well described in the literature.

Since the term metacognition covers a range of knowledge and processes, distinguishing the metacognitive knowledge and processes that are related to and acting on one’s conceptions from other metacognitive knowledge and processes is fruitful in terms of fostering communication and understanding among researchers who study them and teachers who aim to facilitate those processes in classrooms. Thorley (1990) suggested that it is necessary to make a distinction between “metaconceptual” and “metacognitive” components of metacognition. In line with this suggestion, I use the term
“metaconceptual” to denote the metacognitive knowledge and processes that are related to and acting on learners’ conceptions in this study. Metaconceptual knowledge and processes do not involve all kinds of knowledge and processes that are metacognitive in their nature (e.g., problems solving strategies, metacognitive knowledge about one’s memory); rather they constitute only a portion of all metacognitive knowledge and processes. In recent years, an increasing number of researchers started to use the label “metaconceptual” to refer to the thought processes acting on the content of students’ conceptions (see, for example, Mason & Boscolo, 2000; Vosniadou, 1994, 2002, 2003; Wiser & Amin, 2001).

In line with the four key characteristics of metacognitive knowledge and processes presented in the previous section (knowledge about cognition, awareness, monitoring, and regulation), metaconceptual knowledge and processes can be categorized into four components that are distinguishable in terms of their nature and functions: metaconceptual knowledge, metaconceptual awareness, metaconceptual monitoring and metaconceptual evaluation (regulation). These knowledge and processes are briefly described below in order to provide a background for understanding the analysis of data and the purpose of using various instructional activities used in this study.

**Metaconceptual Knowledge**

Metaconceptual knowledge is one’s stable and statable knowledge about concept learning and the factors influencing concept formation. This kind of knowledge is acquired through experience and stored in the memory. It can be retrieved from the memory explicitly or implicitly when needed. Metaconceptual knowledge is similar to
Flavell’s (1979) notion of metacognitive knowledge. The difference between metaconceptual knowledge and metacognitive knowledge lies in their content. The content of metaconceptual knowledge is narrower than that of metacognitive knowledge in that it is only about concept learning and the factors related to concept learning. For example, one’s stored knowledge that “Analogies help me understand concepts,” “My interpretation of daily life experiences influences my learning of the new conception” and “My preexisting knowledge may contradict the new information presented” can be subsumed under metaconceptual knowledge.

An example to the metaconceptual knowledge can be seen in the interview excerpts of a study conducted by Thomas and McRobbie (2001). They investigated the effectiveness of an intervention using a metaphor “learning is constructing” on students’ metacognition and learning processes. Before the intervention, a participant, Debbie, had a metaconceptual knowledge congruent with the transmissionist view of learning. After the intervention it was apparent that her metaconceptual knowledge became more congruent with a constructivist perspective on learning science concepts:

> I don’t learn each concept as a separate and unrelated subject. By linking and relating and processing information I try to end with understanding of each concept in relation to other concepts that I’ve learned. (p. 240)

The excerpt above indicates that Debbie has the knowledge that her existing knowledge structure influences her learning of a new concept. Such a metaconceptual knowledge has potential to lead her to reflect on her existing knowledge and try to make a connection between existing and the new conception. Students’ metaconceptual knowledge may not always facilitate concept learning. Gunstone and Mitchell (1998) argued that students may possess knowledge about learning “that is in conflict with the goals of conceptual
change teaching” (p. 137). Paris and Winograd (1990) argued that students’ learning can be enhanced by becoming aware of their own thinking, and teachers should promote this awareness by discussing cognitive and motivational characteristics of thinking.

*Metaconceptual Awareness*

Metaconceptual knowing is concerned with the learners’ awareness of the elements of one’s existing conceptual structure. The theoretical frameworks that are proposed to explain the change in students’ conceptions (Chi et al., 1994; Posner et al., 1982; Vosniadou, 1994) provide several conceptual elements regarding what learners might be aware of. Metaconceptual knowing is one’s online awareness of existing concepts and elements of conceptual ecology. Learners who answer questions, such as “What do I know about this newly presented topic?” “What kind of experiences do I associate with this concept?” or “What assumptions do I make about this concept?” are making reference to the content of their concept and elements of their conceptual ecology.

The object of reflection in the case of metaconceptual awareness is not a stored knowledge about concept learning, but rather the content of one’s concept itself and relevant elements of one’s conceptual ecology. For instances, one’s statements, such as “I believe that table cannot exert force on the book because static objects cannot exert force” implies that s/he is reflecting on her/his existing conception and related presuppositions, such as there are objects in the world, objects are categorized into animate and inanimate objects, and inanimate objects do not have the capability to exert force.
Vosniadou (2003) argued “students are not always metaconceptually aware. They do not know exactly what they believe and do not understand the hypothetical nature of their beliefs” (p. 402). Vosniadou and Ioannides (1998) claimed that students’ lack of metaconceptual awareness prevents them from reasoning their prior knowledge and forms the basis for the construction of alternative ideas. They also underlined the importance of students’ metaconceptual awareness in the “construction of theoretical frameworks with greater systematicity, coherence and explanatory power” (p. 1222). In order to increase students’ metaconceptual awareness, Vosniadou and Ioannides (1998) pointed out the need to create learning environments in which students can explicitly express their representations and beliefs.

diSessa (1993) argued that novice learners’ intuitive ideas of science are based on their superficial and fragmented interpretations of physical reality, which are called phenomenological primitives (p-rims). Unlike the scientific principles that are general and apply to different contexts, phenomenological primitives are context-dependent and are used by learners as if they are scientific laws. According to diSessa, learning science is a process of organizing fragmented interpretations into a coherent and systematic knowledge structured governed by scientific principles. Learners’ ability to become aware of the different contexts in which a conception is used is critical to the construction of coherent conceptual structures.

**Metaconceptual Monitoring**

Metaconceptual monitoring involves “in the moment” processes that generate information about an ongoing cognitive activity and current cognitive state. While
metaconceptual awareness involves one’s recognition of existing and stored conceptual structure, metaconceptual monitoring entails processes that learners engage in during their attempt to learn a new conception. For example, one’s monitoring of his/her comprehension of a new conception is an online process that produces information for the learner about his/her success or failure to understand a new conception.

One of the conditions of conceptual change presented in CCM is the intelligibility of the new conception. Before conceptual change takes place, the learner must comprehend the meaning of the new conception (Posner et al., 1982). Students’ engagement in comprehension monitoring process is critical in terms of capturing the failures in their understanding of the new conception. A change from using alternative ideas to using scientific conceptions to explain the natural phenomenon requires the learner to recognize the inconsistency between his/her alternative conceptions and the scientific explanation. One of the teaching strategies used to facilitate the change in students’ alternative ideas is promoting cognitive conflict (Scott, Asoko, & Driver, 1992). Although students are presented with information that is inconsistent with their existing conceptions, they may not notice the inconsistency (Vosniadou, Pearson, & Rogers, 1988; Vosniadou, 1999). The effectiveness of cognitive conflict depends on the extent of learners’ monitoring the discrepancy between their existing ideas and the scientific conceptions (Otero, 1998; Scott et al., 1992).

**Metaconceptual Evaluation**

Metaconceptual evaluation involves an individual’s judgmental decisions about existing and new conceptions. In the taxonomies of metacognition, evaluation is
described as one’s evaluation of the usefulness of strategy to achieve his/her goal (Schraw & Moshman, 1995). Since metaconceptual functioning entails processes that act on one’s conceptions, metaconceptual evaluation refers to the learner’s evaluation of his/her conceptions to explain the natural phenomenon. Georghiades (2004) maintained that metacognitive processes “entail more than passive observing.” They require “an element of judgment that is essential in comparing, assessing and evaluating the content or the processes of one’s learning.” He claimed that the information generated from “judgement-laden” reflection will later enable the metacognitive learner to take informed action for rectifying the situation” (p. 371).

According to Hewson (1981), learners’ decisions about the relative plausibility and fruitfulness of competing conceptions determine the likelihood of changing existing conceptions with new ones. Making judgments about the relative plausibility and usefulness of competing conceptions, along with providing justifications for the validity of ideas is considered as metaconceptual evaluation.

Studies Facilitating Conceptual Change through Metacognition

The intertwined nature of metacognition and conceptual change has been acknowledged by various researchers (Baird, Fensham, Gunstone, & White, 1991; Gunstone, 1994; Gunstone & Mitchell, 1998; Hennessey 2003; Pintrich & Sinatra, 2003; Rickey & Stacy, 2000; Vosniadou, 2003). Pintrich and Sinatra (2003) stated that models of conceptual change make the “assumption about the importance of metacognitive awareness” (p. 432). It is apparent that the metaconceptual processes described above require a higher level of thinking that is not easy to achieve through traditional
instruction. There is a need to create learning environments where students are assisted and encouraged to take active control of their own learning, think about, monitor and evaluate their conceptions and the associated components of their conceptual ecology.

There have been encouraging, but only a few investigations that aimed to promote the development of scientific conceptions through facilitating students’ metacognition. The Project to Enhance Effective Learning (PEEL) is one of the research studies that attempted to facilitate students’ conceptual understanding through enhancing their metacognitive skills. This research was influenced from two lines of studies about the quality of science learning conducted during 1970s and 1980s. One line of research showed that students had increasingly poor attitudes as they progressed through their schooling. The other line of research conducted to investigate students' ideas about the natural phenomena showed that students’ alternative conceptions persist in the face of exposure to scientists' explanations (White & Mitchell, 1994).

The main aim of PEEL which was a long-term and “naturalistic” case study was to "foster students' independent learning through training for enhanced metacognition" and to "change teachers' attitudes and behaviours to ones that promote such learning” (Baird & Northfield, 1992, p. iii). Many academics and voluntary groups of teachers participated in this project to develop and investigate classroom approaches that would stimulate and support a more informed, purposeful, intellectually active, and independent student learning. Although the goal of PEEL was to enhance effective learning, the major focus of PEEL and related projects has been on teacher professional development.

Baird (1986), one of the researchers in the PEEL Project, worked with a science teacher and three of his classes for six months to improve students’ metacognitive skills.
At the beginning of the study the students were passive and ignorant about how to improve their learning. Baird provided students with instructional materials, and procedures including questionnaires about learning, discussions about learning and a checklist of questions that encourage them to think metacognitively. Baird concluded that students became more aware of their learning style, became more purposeful, and attained a greater understanding of the content as a result of this intervention. However, there were noteworthy factors that worked against metacognition, including students’ lack of motivation to accept metacognitive activities as a means of learning. White and Gunstone (1989) quoted the following discourse that took place between a teacher and students who participated in the PEEL study:

> We see what this is all about now,’ one said. ‘You are trying to get us to think and to learn for ourselves.’
> ‘Yes, yes,’ replied the teacher, heartened by this long-delayed breakthrough, ‘that’s it exactly.’
> ‘Well,’ said the student, ‘we don’t want to do that.’ (p. 585)

This quote is a salient example illustrating the difficulties in motivating students to engage in the efforts necessary for improving metacognition. White and Gunstone (1989) argued that learners must be “dissatisfied with their present style of their learning” and must “find metacognition plausible, intelligible and fruitful” (p. 585) in order to accept metacognition as a means of effective learning.

Another factor that worked against metacognition was the inconsistent curriculum across different subject areas. Although the normal practices of other teachers in other subject areas did not interfere with the project, students did not find it fruitful to be metacognitive in other classes, since their teachers complained that students were
disrupting the lessons by asking questions. White and Gunstone (1989) also pointed out the type of assessment methods may lead students to adopt short-term goals that make both metacognition and conceptual change “fragile and artificial” (p. 585).

The Project META (Metacognitive Enhancing Teaching Activities) is another research study conducted by Hennessey (1999) to promote metacognition and conceptual change. She developed a system of instruction to improve metacognition within a naturalistic classroom setting. Through collecting data from six cohorts of elementary students (grade 1-6) over a three consecutive academic years, Hennessey aimed to gain insight in the nature of metacognition, the features of higher-level metacognitive thought, processes that lead to change students metacognitive capacities with experience, and the role of pedagogical practices in facilitating changes in metacognition, and changes in students’ conceptual understanding.

Throughout this study, three types of learning activities were used to improve metacognition: poster productions about students’ conceptions, conceptual models designed by the students to represent their conceptual frameworks and technology in the form of word-processing, computer-based graphic programs, and student-generated audio and video recordings. During the use of these instructional practices both small group and large discussions about students’ conceptions took place.

The analysis of the data demonstrated that metacognition is multifaceted in its nature and is within the capabilities of elementary school students. Although Hennessey (1999) was cautious about the conclusion of a causal relationship between the change in students’ metacognitive ability and the change in their conceptions, she argued that metacognition is an integral component of conceptual understanding. She noted that
“metacognitive sophistication and conceptual understanding need to be supported by pedagogical approach that emphasizes reflection on and evaluation of personal claims” (p. 47).

In Beeth’s study (1998), the status language was used as a “metacognitive tool” by the students to reflect on their science conceptions. The participants of the study consisted of 12 fifth grade students attending a small suburban parochial school and their teacher (Sister M. Gertrude Hennessey) who has been working as a science specialist for more than 20 years in parochial schools. In this study, the teacher and the students first negotiated the definitions for the status terms (e.g., intelligibility and plausibility). This negotiation process took about seven weeks for the definition of intelligibility and four weeks for the definition of plausibility.

After a shared understanding of the status terms was established, the teacher continually requested and encouraged students to use the status constructs when talking about their conceptions related to force and motion. The students in this study were able to apply the status language in a powerful way while reflecting on their conceptions. This metacognitive reflection helped students gain deep insight into their conceptions and allowed the teacher to monitor students’ conceptual development to plan future instructional activities. Beeth emphasized the “dynamic role” of the teacher in providing students with metacognitive tools and in creating a learning environment conducive to conceptual change learning.

Wiser and Amin (2001) investigated the role of metaconceptual teaching on the ontological change in four high school students’ conceptions of heat and temperature. The metaconceptual teaching implemented in this study mainly addressed the fact that
students and scientists may use the same word for different conceptual referents. The instructional interventions in this study aimed to make students aware of the two languages and to contrast explicitly their own and scientists’ conceptual frameworks by the use of computer-based conceptual models. Before the implementation of metaconceptual teaching, students understood heat as an intensive physical entity with the essential property of hotness. Metaconceptual teaching allowed students to differentiate among heat as an extensive and temperature as an intensive quantity. After the metaconceptual teaching students were able to describe heat as energy that propagates from the hotter object to the cold one and causes temperature and phase changes. The results of this study indicate that students were able to differentiate hotness and heat in terms their ontological attributes. Although the results of the study indicate students’ engagement in metaconceptual knowing in the form of becoming aware of their ontological presuppositions, the researchers did not explore the nature of students’ metaconceptual knowledge and processes.

The results of the research studies that aimed to promote students’ conceptual understanding through improving their metacognitive reflections are fruitful in terms of providing an empirical support for students’ ability to engage in metacognitive processes. The studies conducted by Beeth (1998) and Hennessey (1999) demonstrated that even elementary school children can think about their ideas and provide reasons for their ideas as long as the teacher uses instructional strategies that support students’ exploration of their own and others’ ideas. These studies also produced promising results about the positive role of metacognition in science learning. However, it is apparent that improving
metaconceptual sophistication in classroom settings takes a lot of time and requires a wide range of instructional activities.

Concluding Remarks

The difficulty students face when learning scientific conceptions that are inconsistent with their existing conceptions has attracted sustained interest from researchers. A common goal of this research is to develop various theoretical frameworks that explain change in students’ conceptions. These theoretical frameworks suggest that conceptual change is not a simple process; rather it is a complicated and multifaceted process in the sense that it not only involves a basic replacement of the existing conception with the new conception, but also a major restructuring of learners’ mental structure and its underlying elements. It is apparent that such a complex restructuring requires higher-order thinking skills, including awareness, monitoring and evaluating existing conceptual structure, its associated elements, the new conception and the context. These processes are metaconceptual in their nature and inherent in the conceptual change process.

The current literature on metacognition has focused mainly on general metacognitive knowledge, strategies, and processes that are not directly related to conceptual knowledge. In this chapter, general components of a taxonomy of metaconceptual knowledge and processes that are derived from theoretical accounts on conceptual change and metacognition are introduced. Four main categories of metaconceptual knowledge and processes were differentiated: Metaconceptual knowledge, metaconceptual awareness, metaconceptual monitoring, and metaconceptual
evaluation. In this study, this taxonomy served as a theoretical guide in developing the instructional interventions, and it also served as a theoretical scheme for differentiating the variations within each category of metaconceptual processes during data analysis. Although the intertwined nature of metacognition and conceptual change has been acknowledged and there have been conducted a few studies which aimed to improve students’ learning of science concepts through facilitating metacognitive processes, the nature of metacognitive processes that are acting on learners’ conceptions remained unexplored. A better description and clarification of the nature of students’ metaconceptual processes through research is critical for understanding how students learn and how their learning can be improved. This study has also potential to examine and strengthen claims about the positive role of metacognition in enhancing students’ conceptual understanding of science.
CHAPTER 3

METHODS AND PROCEDURES

Overview of the Chapter

In this Chapter, I outline the characteristics of the participants and the context under which this study was conducted, and describe the specifics of the research design and data sources that were used to answer the research questions. I also explain the nature of the instructional activities that were employed in this study. Moreover, I summarize the procedures that were followed during collecting data and employment of instructional treatments. This chapter concludes with sections about analysis of the data, validity issues and limitations of the study.

Participants and Context of the Study

This study took place during the first semester of the 2003-2004 academic year. It was conducted in the two classrooms of a high school located in a culturally and economically diverse, 52-square mile area in northeast Ohio. The area has a population of approximately 36,000 people and is located 15 miles from a large university. The student population is fairly homogenous. There are few minority students (10-15%) attending the school, and the socioeconomic status of most students’ families is middle to upper class.
The participants of this study were enrolled in one of the two honor level physics classes instructed by the same science teacher who was willing to implement the designed instructional interventions in his classrooms. Students who wanted to take the physics course were randomly assigned by a computer scheduling program to each class at the beginning of the academic semester so that each class represents a cross-section of the students who registered for this physics course. Each of the teaching approaches (metaconceptual teaching and traditional instruction) was randomly assigned by the researcher to the two classrooms. Students in the experimental group were exposed to metaconceptual teaching interventions while students in the control group were instructed through traditional instruction.

There were 22 students in the experimental group and 23 students in the control group. The participants consisted of grades eleven and twelve students, most of whom were honor-level students, and many of them had not had a physics course in the past. Only two students in the control group and three students in the experimental group had taken a science class in which they studied Newton’s Laws. There were 14 male and 8 female students in the experimental group, and 13 male and 10 female students in the control group. The number of female and male students in each group and the number of students across different grade levels are summarized in Table 3.1.

Three students from the experimental group were selected for intensive case study to explore the nature of metaconceptual processes. The data collected from two of them were used to describe each individual student’s metaconceptual processes as she or he participated in the instructional activities and to portray the changes in his or her
<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>Grade 11</th>
<th>Grade 12</th>
<th>Male</th>
<th>Female</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental Group</td>
<td>22</td>
<td>15</td>
<td>7</td>
<td>14</td>
<td>8</td>
</tr>
<tr>
<td>Control Group</td>
<td>23</td>
<td>10</td>
<td>13</td>
<td>13</td>
<td>10</td>
</tr>
</tbody>
</table>

Table 3.1: Number of students by gender and grade level.

The teacher who implemented the instructional approaches in his classrooms had 15 years experience in physics teaching. As part of his regular instructional practices he used journal writing, hands-on experiments, demonstrations and group and class discussions. In his science classes, he gave students journal prompts that led them to think about their general learning processes. He provided students with journal prompts on a weekly basis and collected and responded individually to each journal entry. Before the instructional interventions began in both groups, he gave students the following journal prompts: “What are your goals and expectations for this course?” “What is your
preferred learning style? In what ways will your learning style enable you to succeed in this class?” and “How do you feel about working in cooperative groups?” In his regular science classes, students work in pre-established groups of 3-5 during performing experiments and but they write lab-reports individually. Both classes were scheduled to meet for 50 minutes five times per week.

The Domain of the Study

In this study, force and motion was selected as the science content area for studying students’ metaconceptual processes. Having force and motion as the main domain, definition of force, Newton’s First Law, Newton’s Second Law, Newton’s Third Law, friction, projectile motion, gravity, and circular motion were covered throughout the instructional interventions in both the experimental and the control groups. Force and motion was chosen as the domain of study because students have a variety of daily life experiences about it, and various research studies have documented that students hold a variety of alternative ideas in this domain (Clement, 1982, 1983; Halloun & Hestenes, 1985b; McCloskey, 1983). Throughout the instructional interventions, the science content was introduced in the following order: Newton’s First Law, Newton’s Second Law, gravity, friction, projectile motion, Newton’s third Law, and circular motion. As necessary, the teacher went back and forth between these topics.

Research Design

The research design of a study is a plan that “guides the investigator in the process of collecting, analyzing, and interpreting observations (Nachmias & Nachmias, 1992, p. 77). Choosing the appropriate research design for a study depends upon the
purpose of the study and the nature of specific research questions (Morse, 2003; Newman, Ridenour, Newman DeMarco, 2003). The purpose of this study was to investigate the effectiveness of instructional interventions, namely, metaconceptual teaching interventions on students’ conceptual understanding in comparison to traditional instruction and the durability of impact of metaconceptual teaching interventions on their conceptual understanding. This research also aimed to gain insight into the nature of students’ metaconceptual processes in relation to their understanding of force and motion concepts during the metaconceptual teaching interventions. In this study, a multi-method research design, which incorporated experimental and case study design, was employed.

Experimental Design

The effectiveness and the durability of the impact of metaconceptual teaching interventions on students’ conceptual understanding were investigated in comparison to the effectiveness of traditional instruction. By the term traditional instruction, I do not mean that the instruction was carried out only in the lecturing format; rather, hands-on experiments, demonstrations, quantitative problem solving and classroom discussions was performed without an explicit attempt to facilitate students’ engagement in metaconceptual processes. An experimental design was employed to statistically compare conceptual understanding by the students who were exposed to metaconceptual teaching interventions with those exposed to traditional instruction. Both groups were taught over an eight-week period. Students in both the experimental and the control groups studied the same content in the same sequence throughout the study.
Students in the experimental group were exposed to several metaconceptual instructional activities, including poster drawing, concept mapping, journal writing, group debate, and group and class discussions. These instructional activities aimed to encourage them to engage in metaconceptual awareness, monitoring, and evaluation and to promote their metaconceptual knowledge about some aspects of conceptual learning. It should be noted that in the experimental group it was not the aim of instructional activities to teach students metacognitive skills, such as metacognitive strategies used to monitor comprehension. Rather, instruction in the experimental group aimed to help students be metaconceptually active through various metaconceptual activities. In addition to the instructional activities listed above, content-rich activities in the form of hands-on experiments, laboratory experiments, demonstrations, and quantitative problem solving were used in the experimental group. At various points throughout the instructional interventions, content-rich activities such as hands-on experiments and demonstrations were incorporated along with group and class discussions and journal writings. The content covered by a demonstration or hand-on activities served in the experimental group as a context and tool for initiating group and class discussion and for prompting students to make journal entries. Quantitative problem solving and laboratory experiments were employed in the experimental group as part of the existing teaching curriculum in the same way used in the control group. Students in the experimental group were also encouraged to discuss some aspects of concept learning. For example, students were prompted to discuss how they learned concepts, why their ideas were different, why was it important to reflect on what they already know, the difference between understanding and believing, and how they know they understand a concept. In the
experimental group, the teacher did not introduce scientific explanations until students could not provide further explanations for the topics covered by the instructional activities. The nature and the purpose of the instructional activities used in the experimental group are explained in detail under the heading of instructional issues.

In the control group, on the other hand, the same science content was explained by the teacher mainly in the lecturing format without any explicit attempt to stimulate students to engage in metaconceptual processes. The instruction in the control group was not carried out only in a lecturing format but, rather, the same set of hands-on experiments, laboratory experiments and demonstrations were performed and quantitative problems were solved. These activities were the same as those used in the experimental group in terms of the content covered. Students in the control group discussed their observation after performing experiments or demonstrations. However, throughout these discussions the teacher did not encourage students to predict the results of the experiments or demonstrations or to compare their initial ideas or predictions with the observed results but rather students simply explained their observations in the form of laboratory reports or verbal comments. The differences in the use of demonstrations and hands-on experiments in control and experiment groups are explained with an example under the heading of instructional issues. In the control group, the teacher provided the scientific explanations in the form of lecturing before the laboratory experiments or just after the demonstrations. Poster drawing, group debate, group discussion, concept mapping, and journal writing were not used in this group.

In this study, students’ conceptual understanding was assessed by the Force Concept Inventory (FCI), a concept test designed to assess students’ conceptual
understanding of force and motion concepts. The FCI was administered to both the experimental and the control groups as a pre-test 10 days prior to the instructional interventions and as a post-test immediately after the instructional interventions. In order to assess students’ delayed conceptual understanding, the FCI was given to both groups 9 weeks after the instructional interventions. A fuller description of the FCI is found under the heading of data sources.

Case Study Design

One of the research questions in this study concerned the nature of students’ metaconceptual processes in relation to their understanding of force and motion concepts. Metacognition does not only involve a static knowledge about cognition, but also “in the moment,” “on-line” processes. This nature of metacognition makes it difficult to assess students’ metacognitive processes through quantitative self-report assessment techniques such as questionnaires, because students may not remember the metacognitive processes that they engage in, they may not understand the questions, or questions may induce responses based on social desirability (Baker & Cerro, 2000; Garner, 1987; Pintrich, Wolters, & Baxter, 2000). It is necessary to employ a research method that allows the researcher to monitor and describe the “in the moment” metaconceptual processes through using multiple data collection techniques.

Among various qualitative research methods, case study design is an appropriate way to provide a “holistic description and analysis of a single instance, phenomenon, or social unit” (Merriam, 1998, p. 27). Yin (2003) defined case study as a “comprehensive” research method that “investigates a contemporary phenomenon within its real-life
context, especially when the boundaries between phenomenon and context are not clearly evident” (p. 13) and that “relies on multiple sources of evidence, with data needing to converge in a triangulating fashion” (p. 14). Case study design is well suited when the “researchers are interested in insight, discovery, and interpretation rather than hypothesis testing” (Merriam, 1998, p. 29) and when they are interested in understanding “process” (Merriam, 1998, p. 33). Having the characteristics listed above, case study design was selected for this research to provide a detailed and rich description about students’ metaconceptual processes as well as change in their conceptual understanding.

Three students were selected from the experimental group to describe the nature of metaconceptual processes. Two of them were chosen to be the focus of the intensive case studies which portrayed each individual student’s metaconceptual processes about their ideas identified before and following the instructional interventions. In order to provide a rich description, data of three students were used to explain the nature and trends of each type of metaconceptual process. Selection of the case study students is explained following this section. The nature of students’ metaconceptual processes and the change in their conceptual understanding of force and motion before and after the instructional interventions were examined by collecting data from multiple sources before, after, and during the instructional interventions. Although data from multiple sources were collected from all students in the experimental group, only the data that belonged to three students selected for the case studies were analyzed. In order to gain insight into the nature of students’ metaconceptual processes in relation to the change in their conceptual understanding of force and motion, this study used data in the forms of video-recordings of classroom discussions, audio-recordings of group discussions (group
discussions about conceptual questions, demonstrations and hands-on experiments, group discussions as students drew posters and explained to each other their concept maps), journal writings, and interviews conducted before and after the instructional interventions.

In summary, a multi-method research design (see Hunter & Brewer, 2003; Morse, 2003) which incorporated qualitative and quantitative research methods was used in this study to investigate the research questions presented in Chapter 1. The design of this study is summarized in Table 3.2. In order to investigate the effectiveness of metaconceptual teaching interventions on students’ conceptual understanding and the durability of the impact of metaconceptual teaching interventions on their conceptual understanding, an experimental design was used. A case study method was employed to examine the nature of students’ metaconceptual processes in relation to the change in their conceptual understanding.

<table>
<thead>
<tr>
<th>Group</th>
<th>Instructional Treatment</th>
<th>FCI-Pre/Post</th>
<th>Interview Pre/Post</th>
<th>Other data sources</th>
<th>FCI-delayed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental</td>
<td>Metaconceptual Teaching</td>
<td>X</td>
<td>O</td>
<td>O</td>
<td>X</td>
</tr>
<tr>
<td>Case study (3 students)</td>
<td>Metaconceptual Teaching</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Control Group</td>
<td>Traditional Instruction</td>
<td>X</td>
<td>O</td>
<td>O</td>
<td>X</td>
</tr>
</tbody>
</table>

Table 3.2: Research design of the study.
Selection of Students for the Case Study

Purposeful sampling (see Merriam, 1998; Patton, 1990) was used to identify the students who were the focus of the case studies. Purposeful sampling involves selection of “information-rich cases” from whom we “can learn a great deal about the issues of central importance to the purpose of the research” (Patton, 1990, p. 169, italics in original). The students for the case study were selected from the experimental group so as to span a range of students’ alternative ideas about force and motion and background in science.

The diversity of alternative ideas about force and motion that students possessed prior to the instructional interventions was one of the selection criteria in choosing the focus students. In doing so, it was aimed to explore metaconceptual processes with content involving a wide range of alternative ideas and to identify the metaconceptual processes of students who changed or did not change their alternative ideas with the scientific ones. Students who held a wide range of alternative ideas regarding force and motion concepts were identified by examining their pre-instructional scores on the FCI. Case study students were selected among those who had low scores on the FCI that was administered prior to the instructional interventions. In doing so, it was assumed that students who had low scores on the FCI had several alternative ideas about force and motion as the distracters of the FCI involves numerous alternative ideas.

The other criterion used for selecting the focus students was students’ backgrounds in physics. Students were selected so as they had different backgrounds in physics (students who had taken physics course in which they studied Newton’s Laws vs. students who had not done so). In order to select the focus students, students who had
taken a physics course that covered Newton’s mechanics and those who had not were examined for their scores on the FCI.

In the experimental group, out of 22 students there were only three who had taken a physics course in which they studied Newton’s Laws. Among these three students, one was from another country and had problems in communicating his ideas in English. Therefore, he was not selected for the case study even though his score on the FCI was the lowest among the students who had taken physics course. Between the other two students, David was chosen for case study since he had the lowest score on the FCI compared to the other student who had taken a physics course before. Among the students who did not take a physics course before, Kelsey and Lisa were students who had low scores on the FCI. Kelsey was a 12\textsuperscript{th} grade student while Lisa was an 11\textsuperscript{th} grade student. Case study students’ pre-FCI scores and their background in physics are tabulated in Table 3.3. In this study, David and Lisa’s data were used to intensely describe the content and types of metaconceptual processes of each individual student in relation to their ideas identified prior to and following the instructional interventions. A detailed description of Kelsey’s case was not provided due to the similarities of the type and content of her metaconceptual processes to those of Lisa. However, Kelsey’s data were used in describing the nature of and trends in each type of metaconceptual process in order to provide rich and diverse examples of each type of metaconceptual process.
<table>
<thead>
<tr>
<th>Students</th>
<th>Physics Course Taken in the Past</th>
<th>Pre-FCI Scores</th>
</tr>
</thead>
<tbody>
<tr>
<td>David</td>
<td>Yes</td>
<td>13</td>
</tr>
<tr>
<td>Lisa</td>
<td>No</td>
<td>8</td>
</tr>
<tr>
<td>Kelsey</td>
<td>No</td>
<td>8</td>
</tr>
</tbody>
</table>

Table 3.3: Pre-FCI Scores and physics background of students chosen for case study.

Data Sources

This study entailed the collection of a wide range of data on students’ conceptual understanding of force and motion and their metaconceptual processes. The following data collection sources were used in this study.

*Force Concept Inventory (FCI)*

In order to compare students in the control and experimental groups in terms of their conceptual understanding and the durability of the impact of metaconceptual teaching interventions on their conceptual understanding, Force Concept Inventory (FCI) was administered to both groups. The FCI is a systematically developed multiple-choice test designed by Hestenes, Wells, and Swackhamer in 1992. This instrument evolved from the earlier Mechanics Diagnostic Test (Halloun & Hestenes, 1985a) and was revised slightly in 1995 by Halloun, Hake and Mosca.

Within the science education community, the FCI is the most widely used and validated diagnostic tool for assessing students’ conceptual understanding of Newtonian mechanics (Hake, 1998; Henderson, 2002). Heller and Huffman (1995) maintained that
the FCI is the “best test currently available” developed to “evaluate the effectiveness of
instruction in introductory physics courses” (p. 510). It has been administered to “more
than 20,000 students and 300 physics classes spanning the range from high school to
graduate school” and the data on the results of the FCI are “growing rapidly” (Hestenes,

The design of the FCI was based on the assumption that students possess a system
of beliefs and intuitions about physical phenomena derived from extensive personal
experience. The FCI developed by Hestenes et al. (1992) consists of 29 multiple-choice
questions developed to probe students’ commonsense beliefs about force concept and
“how these beliefs compare with the many dimensions of Newtonian concept” (Hestenes
et al., 1992, p. 142). The items of the test do not require numerical computation and were
written in non-technical language so that they are meaningful even to the students
without formal training in mechanics. Each item of the test involves one correct option
and four distracters that specifically address commonsense ideas about Newtonian
mechanics.

The items of the FCI cover six conceptual dimensions including kinematics,
Newton’s First Law, Newton’s Second Law, Newton’s Third Law, superposition
principle and kinds of forces. Each of the six dimensions is probed by more than one test
item. Hestenes and Halloun (1995) maintained that all six conceptual dimensions are
“essential” (p. 503, italics in original) to the understanding of Newtonian force concept.
The original version of the FCI was revised slightly in 1995. The revised version of the
FCI involves 30 qualitative conceptual questions. In this study, the revised version of the
FCI was administered to both the experimental and the control groups.
The precursor of the FCI is the Mechanistic Diagnostic Test (MDT; Halloun & Hestenes, 1985a). The test was initially given to introductory-level college students in an open-form. Then, a multiple-choice form was constructed that involved the most common open-ended responses as the choices. The content and face validity of MDT was ascertained by a multi-step procedure. First, the draft of the test was critiqued by physics professors and graduate students. Next, the test was then given to a panel of graduate students to verify agreement on correct responses for the test items. Then, interviews were conducted with introductory physics students who had taken the test to verify their understanding of the questions and the multiple-choice responses. Finally, the responses of students who received “A’s” in introductory physics course were examined for patterns of common misunderstandings.

The MDT was administered to over 1000 students in introductory college physics courses. Reliability for the MDT was established through interviews and statistical analysis. A sample of students who had taken the test were interviewed about their answer choices. The students gave the same answers in their interviews as they had on the written test, and it was found that the students generally had reasons for their choices. Kuder-Richardson reliability coefficients were determined to be 0.86 for pre-test use and 0.89 for post-test use. The KR-20 values for the MDT indicate high reliability.

About half of the questions of the FCI are the same with the items of the MDT. Hestenes et al. (1992) did not follow the procedures they used for checking the validity of MDT. However, since the publication of the FCI in 1992, the items of the test have been examined by several physics professors (Hestenes & Halloun, 1995). The authors of the test had not reported serious concerns about conceptual dimensions covered the FCI or
about wordings or diagrams used in the test items. One of the authors (Hestenes) of the FCI interviewed 16 first-year graduate students beginning graduate mechanics on the questions they failed to answer. Among the 16 graduate students, 5 of the American students and 5 of the foreign students showed difficulty in understanding the text of the two questions, since they overlooked prepositions which have a critical role in determining the meaning of the test item. These test items were discarded from the original version of the inventory (Hestenes et al., 1992). Hestenes and Halloun (1995) concluded that the “face validity” of the FCI is “beyond reasonable doubt” (p. 503, italics in original). As a result of interviews with the students, Hestenes and Halloun observed that students “usually have definite reasons for their choices” (p.504) of the alternatives for the items of the FCI. In order to reduce the probability of choosing a correct response for “Non-Newtonian reasons” FCI was designed in a way that each of the six conceptual dimensions is probed by more than one test item involving different contexts and viewpoints and it involves “powerful distracters” gathered from extensive interviews with students (Hestenes & Halloun, 1995, p. 504).

Hestenes et al. (1992) did not use statistical analysis to establish test reliability of FCI. They demonstrated the reproducibility of FCI by obtaining similar FCI scores from similar populations. They found that the post-test averages from classes with over a thousand students in introductory classes instructed in the traditional style by seven different professors were remarkably similar. The post-test averages were between 60 and 64% correct. The reproducibility of the FCI results obtained from similar classes was also demonstrated by Hake (1998) who compared the performance of 6542 students from 62 introductory physics classes.
In this study, FCI that was slightly revised in 1995 was used as a pre-test, post-test and delayed test. This test was administered to control and experimental groups 10 days before and following the instructional interventions. In order to assess the durability of the impact of metaconceptual teaching interventions on students’ conceptual understanding the test was given to both groups as a delayed-test nine weeks after the instructional interventions about Newtonian mechanics was ended in both groups. Students were given one class period to complete the test.

The reliability of the FCI was determined by Kuder-Richardson 20 reliability coefficient in this research. For pre-FCI KR-20 was found to be 0.53 for the control group and 0.61 for the experimental group. For post-FCI, KR-20 was 0.73 and 0.83 for the control and experimental groups, respectively. For the delayed-FCI, KR-20 was to be 0.76 for the control group and 0.86 for the experimental group. The KR-20 values found for post- and delayed-test use indicates high reliability of the FCI.

Interviews

Interviewing is one of the data collection methods that is used when “we cannot observe behavior, feelings or how people interpret the world around them” (Merriam, 1998, p. 72). According to Patton (1990), the aim of conducting interview is to find out what is “in and on someone else’s mind” (p. 278). Merriam (1998) described interviewing as “the best technique to use when conducting intensive case studies of a few selected individuals” (p. 72).

The third research question of this study is concerned with gaining insight into the nature of students’ metaconceptual processes in relation to the change in their conceptual
understanding of force and motion. As this research question indicates, the focus of this question was not only to identify students’ metaconceptual processes, but also to portray the changes in students’ force and motion ideas and their metaconceptual processes related to those ideas. Therefore, besides the identification of students’ metaconceptual processes, the changes in students’ conceptual understanding of force and motion concepts prior to and after the instructional interventions needed to be assessed. Students’ conceptual understanding of force and motion concepts was assessed by conducting person-to-person semi-structured interviews before and after the instructional interventions. In order to gain insight into the trends in different types of metaconceptual processes, students were also interviewed about some aspects of their concept learning. Pre-instructional interviews were conducted after the administration of pre-FCI and in a ten-day period prior to the instructional interventions. Post-instructional interviews were conducted two weeks after the instructional interventions. Post-instructional interview could not be performed immediately after the instructional interventions because students had a two-week vacation that started a day after the instructional interventions ended in both groups.

In order to investigate the change in students’ conceptual understanding, only students who were selected for the intensive case studies were interviewed. Students were asked open-ended questions (see interview protocol in Appendix B) to determine how well they understood force and motion concepts, to identify their alternative ideas, areas of confusion, and gaps in understanding of force and motion concepts. One of the open-ended questions aimed at exploring how students define force and what characteristics they attribute to this concept. The other interview questions involved presenting students
with a series of situations in the forms of pictures, demonstrations, or verbal explanations. Students were asked to explain the forces acting on and motion of objects within the context of the provided situations. Many of the interview questions were similar to those used in the clinical interviews conducted in previous research that explored students’ conceptual understanding of force and motion (Clement, 1983; diSessa, Elby, & Hammer 2003; McCloskey, 1983). Three of the interview questions (questions 6, 7, and 8) are similar to the questions in the FCI (Hestenes, Wells & Swackhamer, 1992).

Each student selected for the case study was provided with the same prompts and questions. However, additional questions were asked during the interviews to gain deeper insight into the emerging views of the interviewees about the given situation. These additional questions are presented in the interview protocol (see Appendix C) under the heading of probing questions. Students were requested to think aloud as they worked on the questions. In the post-instructional interview, in order to explore why students changed their ideas, they were confronted with their ideas about force and motion that they held prior to the instructional interventions. After confronting students’ with pre-instructional ideas, they were asked whether they still held the same idea and why they changed their idea.

The trends in different types of metaconceptual processes were assessed by asking students open-ended questions about some aspect of their science concept learning (see part II in Appendix B) after the instructional interventions. The aim of the interview questions was to explore what justification standards students use while evaluating different ideas, whether they still use their initial ideas, their perception of the differences between their learning in this class and in other science classes, and in what ways their
science ideas have changed in this class. In order to create a context for the students to think about their learning of science concepts, scenarios within the interview questions were created.

Additional Data Sources

The third research question of this study required the assessment of metaconceptual processes that students engaged in during the instructional interventions. The nature of metaconceptual processes as “on-line” or “in the moment” processes makes it difficult to assess metaconceptual processes through questionnaires or interviews. The problems associated with the assessment of metacognition through interviews or questionnaires have been well documented. Verbal reports of all types are subject to many constraints and limitations (Baker & Cerro, 2000; Garner, 1987; Pintrich, Wolters, & Baxter, 2000). For example, participants may not be able or willing to express their thoughts and experiences, they may not understand the questions, or questions may induce responses based on social desirability. Students’ failure to remember cognitive events and their lack of verbal facility to explain cognitive and metacognitive processes may also influence the accuracy of the data collected through verbal reports (Garner, 1987). Pintrich et al. recommended the use of think-aloud techniques to assess metacognition. Think-aloud techniques may be useful to observe metacognitive processes while solving problems. However, within the context of this study, it is very difficult to implement think-aloud technique in classroom settings during the instructional interventions.
One proposed solution to the problems regarding to the assessments of metacognition is to use multiple methods that do not share the same source of errors (Garner, 1987). In this study a wide range of data was collected from different sources to assess students’ metaconceptual processes as they participated in the metaconceptual instructional interventions. The data regarding students’ metaconceptual processes were derived from the following sources: students’ journals, audio-recordings of group-based activities, and video recordings of classroom discussions. Audio-recordings of group-based activities involved students’ discussions on conceptual questions, demonstrations, hand-on experiments regarding force and motion concepts, group debate that entailed choosing an idea from several alternatives an defending it, and group conversations that took place as students drew posters and explained to each other their concept maps. These data sources are necessary for capturing students’ “in the moment” or “online” metaconceptual processes in the form of students’ verbal statements and written comments without interrupting the use and the flow of instructional activities. Collecting data from multiple sources enabled me to observe a wide range of metaconceptual processes based on the nature of prompts that were used for journal writings, group-based activities, and class discussions.

Data from the sources mentioned above were collected from the students in the experimental group. Only the data collected from the students who were the target of the intensive case study were analyzed. The aim of collecting data from other class members was to ensure that the target students were not overwhelmed by the intensive focus of the researcher. It also served as a contingency measure to ensure that I had data from other students in case students who were the focus of the case studies withdrew from the study.
The lessons that take place in the control class were also videotaped to be used as a permanent record of the classroom events. Field notes were kept in both the experimental and the control groups to record the classroom events, describe the research site, and identify the segments related to metaconceptual processes on the audio or videotape to review for data analysis later. During group-based activities in the experimental group, two of the groups were asked to go to the recording centers located at two different sections of the classroom for ensuring the quality of the recordings.

In summary, in this study data were collected from multiple sources. The sources of data along with the purpose and chronology of the data collection and the target group the data of whom was analyzed are summarized in Table 3.4. It is worth noting that although lessons in both the experimental and the control groups were video recorded and data in the form of journal writing, audio-recordings of group-based activities was collected from students in the experimental group, only the relevant sections of data which belonged to the students selected for case study were transcribed.

Timeline and Procedures Followed During Data Collection

As the researcher of this study, I was present in the both the experimental and the control groups seven weeks before the instructional interventions began in order to become acquainted with the research site and participants of the study. Throughout the study, I was responsible for administrating the tests, conducting semi-structured interviews and collecting the data in the all needed forms. I administered the FCI about ten days before the instructional interventions. After examining students’ responses to the FCI, I selected the target students who were the focus of the case studies. I interviewed
<table>
<thead>
<tr>
<th>Data Sources</th>
<th>Purpose of Data Collection</th>
<th>Target group</th>
<th>Chronology of Data Collection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Force Concept Inventory</td>
<td>Assessment of students’ conceptual understanding of force and motion concepts</td>
<td>Experimental and control group</td>
<td>10 days before and immediately after and 9 weeks after the instructional interventions</td>
</tr>
<tr>
<td>Interview</td>
<td>Assessment of students’ conceptual understanding of force and motion concepts and their concept of learning (used to explain the trends, if any, in metaconceptual processes)</td>
<td>Students who were focus of the case studies</td>
<td>In a 10-day period before and 2 weeks after the instructional interventions</td>
</tr>
<tr>
<td>Students’ journals</td>
<td>Assessment of students’ metaconceptual processes</td>
<td>Students who were focus of the case studies</td>
<td>During the instructional interventions</td>
</tr>
<tr>
<td>Video recording of class discussions</td>
<td>Assessment of students’ metaconceptual processes</td>
<td>Students who were focus of the case studies</td>
<td>During the instructional interventions</td>
</tr>
<tr>
<td>Audio recordings of group-based task (e.g., group discussions, group debate, poster drawing, and description of concept maps)</td>
<td>Assessment of students’ metaconceptual processes</td>
<td>Students who were focus of the case studies</td>
<td>During the instructional interventions</td>
</tr>
</tbody>
</table>

Table 3.4: Data sources.
those students in a ten-day period prior to the instructional interventions. I conducted the interviews during students’ free time or lunchtime so that the interviews did not cause the target students to miss the regular classroom instruction. Interviewing each focus student about her/his conceptual understanding, and some aspects of concept learning took about one to one and a half hours. In a ten-day period, I interviewed each student twice. The focus of the first interview was to assess students’ conceptual understanding while the focus of the second interview was to assess students’ ideas about concept learning. I administered the FCI as a post-test to both classrooms a day after instructional interventions in both groups ended. I conducted the post-interviews two weeks after the administration of the FCI due to students’ two-week long vacation. I gave the FCI as a delayed test nine weeks after the instructional interventions ended. Each time the FCI was administered students were given a class period to complete the test, and they were asked to sit as far apart from each other as possible.

During the instructional interventions, a video camera was set at the back of the classroom before students arrived and it was kept running during the whole instruction in both groups. There were six pre-established groups of student in the experimental group. For four groups, I placed the audio-recorder on students’ own tables to record their group-based activities. For two groups, I created two audio-recording centers at different locations of the classroom to ensure the quality of the audio-recordings. I asked students to lend me their journal books during the instructional interventions to make copies.
Instructional Issues

In this study, the instruction was centered on the use of content-rich instructional tasks and metaconceptual instructional activities. The use of content-rich tasks in experimental and control groups and use of the metaconceptual instructional activities are described below.

Use of Content-Rich Instructional Tasks in Experimental and Control Groups

The content-rich instructional tasks consisted of a collection of content-specific activities related to Newton’s Laws. In both groups, they were used to build a set of experiences for students about force and motion concepts. The content-rich instructional tasks involved demonstrations, laboratory experiments, hands-on experiments, and quantitative problem-solving. For example, pushing a book across the table, dropping a heavy and light object from the same height at the same time, a student on a skateboard pushing another student and measuring the amount of forces needed to start an object in motion and to keep the object moving at a constant speed are examples of the content-rich tasks.

In the experimental and control groups, the same set of content-rich tasks was used. There were no variations in the use of laboratory experiments and quantitative problem solving activities in the experimental and control groups. In both groups, identical quantitative problems were solved and the same laboratory experiments about friction, Newton’s Second Law, and projectile motion were performed in the same way as part of the teacher’s existing curriculum without any explicit attempt to facilitate metaconceptual processes. On the other hand, there were some differences in the use of
demonstrations and hands-on experiments in the experimental and control groups. In the experimental group, hands-on experiments and demonstrations were incorporated with journal writing along with group and class discussions, so that the science content covered by these tasks served as prompts to facilitate students’ metaconceptual functioning. In the control group, however, demonstrations and hands-on experiments were used by the teacher as a tool to introduce a new scientific topic or as supplementary instructional tasks to further clarify the science content explained by the teacher in the lecturing format.

The demonstrations used to introduce Newton’s Third Law serve as a concrete example of how demonstrations are incorporated differently in the teaching sequence of experimental and control groups. To teach Newton’s Third Law, four different demonstrations were employed by the teacher in both the experimental and the control groups: (a) a student standing on a skateboard pushes on a wall; (b) one student pushes another student with identical weight while both of them are standing on skateboards; (c) one student pushes another student who weighs less while both of them are standing on skateboards; and (d) a student standing on the floor pushes a shopping cart as they move together at a constant speed while another student standing on a skateboard pushes a shopping cart. In the experimental group, before the teacher demonstrated these situations, students were asked to write in their journals their predictions about the forces acting on people and objects in each situation and the direction of their movement. Then, students discussed their ideas and their reasons behind their ideas within their groups. After group discussions, as the teacher performed demonstrations with the help of the students, students were requested to observe the direction of movement and compare the
distance traveled by each student. After the demonstrations, students were asked to discuss their observations, the consistency between their observations and their initial arguments, and in what ways their observations support or refute their initial predictions. Students were also encouraged to provide a theoretical explanation for their observations. After the group discussion, students summarized their ideas to the whole class. At this point, the teacher did not introduce Newton’s Third Law until students could not provide different theoretical ideas regarding the situations. In relation to this activity, students were prompted to write a journal about their initial ideas, the consistency between initial ideas and their observations, any limitations of their ideas, and changes in their ideas. While this teaching sequence was followed by the teacher in the experimental group, the teacher directly started performing the same demonstrations in the control group. As the teacher demonstrated the situations, he explained the direction of the movement and compared the distance traveled by each student. After the demonstrations, he asked students to summarize their observations to the whole class and introduced Newton’s Third Law by lecturing. Students in the control group did not write journal related to this task.

Traditional Instruction

The main method of instruction in the control group was lecturing. The teacher introduced science content by lecturing without any explicit attempts to facilitate students’ metaconceptual processes. Compared to the students in the experimental group, students in the control group were mostly passive, listening the teacher’s instruction. The teacher outlined the scientific content on a transparency as he explained it. At the end of
introducing each science topic, students were asked whether they had questions or needed further clarifications about the explained content.

The instruction was supplemented by the content-rich tasks (e.g., demonstrations, hands-on experiments, laboratory experiments, and quantitative problem solving) in a way explained in the above section. Quantitative problems were solved and laboratory experiments were performed after the science content was introduced by the teacher. Representative problems, which required calculations, were first solved by the teacher. Students were provided with handouts of quantitative questions about force and motion. They also worked on the problems chosen from their textbooks. They were asked to solve the problems either at home or in class. While performing laboratory experiments, students worked in pre-established groups. Students discussed their observations after performing experiments or demonstrations. However, they were not asked to predict the results of the experiments or demonstrations or to compare their initial ideas or predictions with the observed results. Rather, students simply explained their observations in the form of laboratory reports or verbal comments.

While conceptual questions or situations (e.g., forces acting on a book at rest on a table) were discussed in groups and ideas about them were written in journals in the experimental group, the same conceptual questions and situations were directly explained by the teacher without asking students to discuss and write their ideas. Poster drawing, group debate, group discussion, concept mapping, and journal writing were not used in this group.
Metaconceptual Teaching Activities: Aims and Procedures

In the experimental group, in order to facilitate students’ engagement in metaconceptual knowledge and processes several types of instructional activities (i.e., poster drawing, concept mapping, group debate, group and class discussion, and journal writing) were employed. These instructional activities provided an opportunity for the students (a) to become aware of their existing conceptions, the associated ontological presuppositions, past experiences, and contexts in which concepts are used; (b) to make reference to their past ideas; (c) to monitor their understanding of a new conception, other people’s ideas, the consistency between existing ideas and information coming from other sources, and the change in ideas; and (d) to evaluate competing conceptions in the forms of describing why an idea explains a situation better than another one, reflecting on the plausibility and usefulness of ideas, providing justifications for the validity of ideas, and realizing the limitations of ideas. Students were also encouraged to discuss some aspects of concept learning to help them acquire knowledge about their learning process.

Different types of activities with different prompts were used so that students did not treat them in a mechanistic and monotonous way. In the experimental group, problem solving and laboratory experiments were employed in the same way as in the control group. Unlike in the control group, in the experimental group the teacher did not introduce scientific content until students could not provide further explanations for the topics covered by the instructional activities.

The activities used in this study were developed by me with the cooperation of the classroom teacher. Necessary modifications and additions were made based on the students’ needs or teacher’s feedbacks. The nature and the purpose of the various types of
instructional activities used in the experimental group are described below. The content covered by particular activities and the metaconceptual processes intented to be promoted by them are summarized in a table following the description of the types of instructional activities.

*Poster Production*

Poster drawing was used to facilitate students’ engagement in metaconceptual awareness and metaconceptual monitoring. Students were prompted to produce posters twice during the instructional interventions: at the beginning and near the end of instructional interventions. At the beginning of the instructional interventions, in order to help students become metaconceptually aware of their existing ideas, ontological presuppositions, and past experiences they were asked to produce posters about their group’s understanding of force along with examples from their daily experiences and a list of the characteristics of force concept (see Activity 1 in Appendix C). After drawing posters, each group presented their poster to the whole class.

In order to make students aware of their initial ideas and the conceptual entities that they did not know before and also to help students monitor the changes in their ideas about force concept, the posters initially produced by the students were returned to them near the end of instructional interventions (see Activity 12 in Appendix C). Students were asked to make necessary changes in their initial posters and explain why they wanted to change those ideas. After students made changes in their initial posters, they were asked to present the changes they made in their posters to their classmates.
Journal Writing

Journal writing provided students in the experimental group with the opportunity to engage in different types of metaconceptual processes. The journal prompts were chosen so that they encouraged students to (a) make reference to their existing conceptions, (b) recognize their past idea, (c) examine the reasons why they were attracted to their views, (d) monitor their understanding and the differences in different views, (e) make judgments on the validity of competing ideas, (f) recognize the limitations of their views, (g) look for consistency among their initial and current ideas across different contexts, and (h) monitor the changes in their ideas. Students were also asked to write about concept learning. For example, they were asked to write about the conditions under which they changed their ideas, and they were prompted to compare the applicability and generalizability of scientific principles and their own ideas. Journal writing was used as a medium for private reflection. This characteristic of journal writing enabled shy and introverted students, who were not willing to share their ideas with their classmates, to engage in metaconceptual awareness. Journal entries were also used as a permanent record of students’ initial ideas about a physical phenomenon when they were asked to compare the consistency of their current and initial ideas across different situations (see journal prompt 11 in Appendix C).

Students were requested to write journals before, after or as part of a demonstration, poster drawing activity, group debate, and group or class discussion. Journal prompts used before or as part of the instructional activities were used as means of promoting students’ awareness of their own ideas. For example, in order to encourage students to become aware of their ideas, they were asked to write about their predictions
about the forces acting on objects and explain their reasons for their predictions before they discussed the physical phenomenon in their groups. While journal entries prompted before or as part of the instructional activities were written in class, journal entries prompted after the instructional activities were assigned as homework. Journal prompts given as part of instructional activities can be seen within those activities (see Appendix C). Journal prompts provided after the instructional activities are provided in Appendix C. It is worth noting that journal writing was not a totally novel activity in this physics class. Prior to the instructional interventions, the teacher provided students in both groups with journal prompts about their general learning processes, such as their learning style, their goals and expectations for this class, and ideas about working in groups. None of the journal prompts given before the instructional interventions prompted students to engage in a metaconceptual process that is acting on a particular conception.

Group Debate

Group debate was used to help students become aware of their ideas and associated presuppositions about a physical phenomenon as they discuss their ideas with other students who hold different ideas. This activity also aimed to enable students to evaluate competing ideas in the form of making judgmental decisions about ideas as they defend one idea against other ideas. In this type of activity, students were asked a conceptual question with multiple alternatives. Students were requested to choose one among the several options that represented best their ideas. Group debate activities used in this study were activities 3, 5 and 7 (see Appendix C). From students who chose different responses, groups of 3-5 students were formed. They were asked to explain each
other why the alternative they chose was the best explanation for the physical phenomenon presented in the question

*Concept Mapping*

Concept mapping was used to help students see the relationships among conceptual entities. Students were given a number of terms, such as \( F_{\text{net}}=0 \), \( F_{\text{net}}<0 \), \( F_{\text{net}}>0 \), constant speed, at rest, motion, balanced and unbalanced forces, acceleration, and deceleration (see concept map activity in Appendix C). They were asked to arrange the terms into a map so that the map represented the relationships between the terms. Throughout the instructional interventions, students were asked to produce concepts maps once, after Newton’s laws were introduced. After students drew concept maps, they explained their concept maps to other students in their groups and made comparisons among the concept maps produced by other students. By drawing concept maps and sharing them with other students, students were encouraged to become aware of the relationships among various conceptual entities and to monitor the ideas of other students in their group.

*Group Discussions*

Students in groups of three or four were encouraged to discuss their ideas about a given situation (e.g., forces acting on a ball which was tossed up) or before performing a demonstration or hands-on experiment (e.g., measuring the force needed to start an object’s motion and to keep it moving at a constant speed). The nature of the prompts used to facilitate group discussions about a given situation aimed to promote various forms of metaconceptual awareness, metaconceptual evaluation, and metaconceptual
monitoring. For example, the prompts used to facilitate group discussions not only made students’ ideas explicit within one context but they allowed students to recognize their own ideas across different situations. As students discuss their ideas about a given situation, they became aware of their experiences, ontological presuppositions and conceptual entities that they had not known. As they defended their ideas against the ideas of other students, they engaged in metaconceptual evaluation in the forms of explaining why one idea explains the situation better than other ideas and providing justifications for ideas.

In group discussion activities incorporated with demonstrations or hands-on experiments, students were asked to make predictions about the physical phenomenon. Before the demonstrations and hands-on activities were performed, students discussed their predictions in pre-established groups of 3-5 students. After they observed the demonstrations and hands-on experiments, they were asked to compare their initial predictions with the observed results. In doing so, students engaged in monitoring the consistency of their ideas/predictions with an observed phenomenon.

After the group discussions, students summarized the ideas that they discussed in their groups to the whole class. As students summarized their ideas, the teacher outlined them on a transparency to confront students with their initial ideas later in class discussions. Activities 2, 4, 6, 8, 10, and 11 are the group discussion activities (see Appendix C).
**Class Discussions**

In this study, classroom discussions were carried out frequently at various points throughout the instructional sequence. Students were encouraged to discuss their ideas after group-based activities (group debate activities and group discussion activities, poster drawing activity), after demonstrations and hands-on experiments, and when students asked questions to clarify a physical phenomenon. Classroom discussion carried out after demonstrations or hands-on experiments were aimed at encouraging students to develop a theoretical framework that explains what they observed and to compare their initial thoughts with their observations. Class discussions performed after the group-based activities were aimed at facilitating students to recognize their own ideas and make students defend ideas by providing justifications.

At one point after Newton’s First and Second Laws were introduced, students were confronted with their initial ideas that were written on a transparency by the teacher as students summarized their group’s ideas. They were asked in what ways those ideas were different from scientific ideas and what limitations their initial ideas had. This was aimed at promoting students’ engagement in metaconceptual awareness of their initial ideas, monitoring the consistency between their initial ideas and scientific ideas, and metaconceptual evaluation.

Throughout the class discussions, the teacher did not introduce scientific knowledge until students could not provide further explanation. Until the introduction of the scientific knowledge, he did not make statements about the validity of students’ ideas. He prompted students in a way to help students to explicitly state and clarify their ideas and explain why an idea made more sense compared to another ideas. Examples of the
discussion prompts he used are: “Could you explain what you mean by….?” “David thinks…. What do you think about his idea?” “Do you agree with David?” “Why do you disagree with him?” “Why do you think your idea is better?” “What reasons do you have?” “Is it [the result of a demonstration] different from what you thought?” “Do you agree with your group’s idea?” “Do you understand what your friend just said?”

At some points throughout the teaching sequence, students were encouraged to discuss some aspects of concept learning to promote their metacognitive knowledge about concept learning. They were prompted to discuss how they learned concepts, why their ideas were different, why it was important to reflect on what they already know, advantages of using scientific ideas over using an alternative idea, the difference between understanding and believing, and how they know they understand a concept. For example, after students’ poster presentations about students understanding of force, the teacher noted that there were variations in students’ ideas about force. Students were prompted to discuss why their ideas were different. Throughout the same discussion the teacher maintained that scientific ideas might sometimes be different from students’ own ideas. In the rest of the discussion, students were prompted to discuss why it is important to learn scientific ideas. At other points throughout the instructional interventions, students were asked to differentiate the terms believing and understanding. They were asked to discuss when they know they understood and believed in ideas. Near the end of the instructional interventions, the teacher prompted students to discuss what they thought about discussing and writing about initial ideas. He briefly described the knowledge change in scientific communities and asked students to discuss whether they observed a similar trend in their learning in this class.
Scientific Content and Types of Metaconceptual Processes Facilitated by Journal Writing and Group-Based Activities

The different types of instructional activities used in the experimental group to facilitate students’ metaconceptual functioning are described in the previous section. Table 3.5 shows the content covered by each group-based activity and journal writing, and also the types of metaconceptual processes that were facilitated by each activity. Activities and journal prompts are presented in the order used throughout the instructional interventions.

Treatment Verification

Throughout the instructional interventions, I observed both the experimental and the control groups to ensure that the teacher implemented the developed instructional interventions in the intended way. I kept field notes and the instruction in both groups was videotaped. While administering the FCI, I was present in the classrooms and made sure that the FCI was distributed to all students participating in the study. After administering the FCI, I collected all question booklets. Throughout the study, the name of the FCI was not mentioned to avoid students’ access to it through different sources.

The instructional activities were developed by me with the cooperation of the teacher. Before instructional interventions began, we went through all instructional activities. I made necessary modifications and additions based on the teacher’s feedbacks. Throughout the instructional interventions, the teacher and I met each week to discuss the nature and sequence of the instructional activities used in both groups. We made modifications in the developed instructional activities based on the emerging needs of the
<table>
<thead>
<tr>
<th>Activities and Journal Prompts</th>
<th>Type of Activity</th>
<th>Science Content</th>
<th>Metaconceptual Processes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activity 1</td>
<td>Poster Drawing</td>
<td>Force concept in general, entities associated with force.</td>
<td>Metaconceptual awareness of existing ideas, experiences, ontological presuppositions.</td>
</tr>
<tr>
<td>Journal Prompt 1</td>
<td>Journal Entry</td>
<td>Force concept in general, entities associated with force.</td>
<td>Monitoring ideas of other people.</td>
</tr>
<tr>
<td>Activity 2</td>
<td>Group Discussion/ Journal Entry</td>
<td>Forces acting on objects moving horizontally, relationship between force and motion.</td>
<td>Metaconceptual awareness of existing ideas.</td>
</tr>
<tr>
<td>Journal Prompt 2</td>
<td>Journal Entry</td>
<td>Forces acting on objects moving horizontally, relationship between force and motion.</td>
<td>Monitoring the consistency between existing ideas and ideas of other people, metaconceptual evaluation.</td>
</tr>
<tr>
<td>Activity 3</td>
<td>Group Debate/ Journal Entry</td>
<td>Forces acting on an object moving on a frictionless surface.</td>
<td>Metaconceptual evaluation, metaconceptual awareness of existing ideas, ontological presuppositions, and contextual differences.</td>
</tr>
<tr>
<td>Journal Prompt 3</td>
<td>Journal Entry</td>
<td>Forces acting on an object moving on a frictionless surface.</td>
<td>Monitoring ideas of other people, monitoring the consistency between existing ideas and ideas of other people, metaconceptual evaluation and monitoring changes in ideas.</td>
</tr>
<tr>
<td>Journal Prompt 4</td>
<td>Journal Entry</td>
<td>Newton’s First Law.</td>
<td>Monitoring understanding of an idea, metaconceptual evaluation, monitoring changes in ideas, metaconceptual awareness of initial ideas, and monitoring the consistency between initial ideas and new idea.</td>
</tr>
<tr>
<td>Journal Prompt 5</td>
<td>Journal Entry</td>
<td>Analogy between Newton’s First Law and change in ideas, conditions under which ideas change.</td>
<td>Metaconceptual knowledge about one’s concept learning.</td>
</tr>
</tbody>
</table>

Table 3.5: The aims and science contents of instructional activities.

(continued)
Table 3.5 continued

<table>
<thead>
<tr>
<th>Activities and Journal Prompts</th>
<th>Type of Activity</th>
<th>Science Content</th>
<th>Metaconceptual Processes</th>
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<tbody>
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<td>Activity 4</td>
<td>Group Discussion/ Journal Entry</td>
<td>Gravity.</td>
<td>Metaconceptual awareness of existing ideas.</td>
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<td>Journal Prompt 6</td>
<td>Journal Entry</td>
<td>Gravity.</td>
<td>Monitoring understanding of an idea, monitoring the consistency between existing idea (predictions) with observed experience, metaconceptual awareness of initial ideas, monitoring changes in ideas, and metaconceptual awareness of what you did not know.</td>
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<tr>
<td>Activity 5</td>
<td>Group Debate/ Journal Entry</td>
<td>Forces acting on an object at rest</td>
<td>Metaconceptual awareness of existing ideas and ontological presuppositions, and metaconceptual evaluation.</td>
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<td>Journal Prompt 7</td>
<td>Journal Entry</td>
<td>Forces acting on an object at rest</td>
<td>Metaconceptual awareness of initial ideas, monitoring understanding of an idea, metaconceptual evaluation, metaconceptual awareness of existing (current) ideas, and monitoring changes in ideas.</td>
</tr>
<tr>
<td>Activity 6</td>
<td>Group Discussion/ Journal Entry</td>
<td>Forces resisting the horizontal motion of an object, amount of force needed to start object’s motion and keep it moving at constant speed.</td>
<td>Metaconceptual awareness of existing ideas, metaconceptual awareness of contextual differences, monitoring ideas (experiential observation) coming from other sources, and monitoring the consistency between existing ideas/predictions and new experience (observation).</td>
</tr>
<tr>
<td>Activity 7</td>
<td>Group Debate/ Journal Entry</td>
<td>Forces acting on an object moving vertically.</td>
<td>Metaconceptual awareness of existing ideas and metaconceptual evaluation.</td>
</tr>
<tr>
<td>Journal Prompt 8</td>
<td>Journal Entry</td>
<td>Forces acting on an object moving vertically.</td>
<td>Metaconceptual awareness of initial ideas, metaconceptual awareness of initial ontological presuppositions, metaconceptual awareness of contextual differences, metaconceptual evaluation, monitoring the consistency between existing ideas and ideas of other people.</td>
</tr>
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</table>
Table 3.5 continued

<table>
<thead>
<tr>
<th>Activities and Journal Prompts</th>
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<th>Metaconceptual Processes</th>
</tr>
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<tr>
<td>Activity 8</td>
<td>Group Discussion/ Journal Entry</td>
<td>Projectile motion.</td>
<td>Metaconceptual awareness of existing ideas and metaconceptual awareness of contextual differences.</td>
</tr>
<tr>
<td>Journal Prompt 9</td>
<td>Journal Entry</td>
<td>Projectile motion.</td>
<td>Metaconceptual awareness of initial ideas, metaconceptual evaluation, monitoring changes in ideas.</td>
</tr>
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<td>Activity 9</td>
<td>Concept Mapping</td>
<td>Force and motion.</td>
<td>Metaconceptual awareness of existing ideas, monitoring consistency between existing ideas and ideas of other people.</td>
</tr>
<tr>
<td>Activity 10</td>
<td>Group Discussion/ Journal Entry</td>
<td>Newton’s Third Law</td>
<td>Metaconceptual awareness of existing ideas, metaconceptual awareness of contextual differences, monitoring ideas (experiential observation) coming from other sources, and monitoring the consistency between existing ideas/predictions and new experience (observation).</td>
</tr>
<tr>
<td>Journal Prompt 10</td>
<td>Journal Entry</td>
<td>Newton’s Third Law</td>
<td>Metaconceptual awareness of initial ideas, monitoring understanding of ideas, metaconceptual evaluation, monitoring the consistency between initial ideas a new experience, monitoring changes in ideas.</td>
</tr>
<tr>
<td>Activity 11</td>
<td>Group Discussion/ Journal Entry</td>
<td>Circular motion.</td>
<td>Metaconceptual awareness of exiting ideas.</td>
</tr>
<tr>
<td>Journal Prompt 11</td>
<td>Journal Entry</td>
<td>Force acting on objects in different situations.</td>
<td>Metaconceptual awareness of initial ideas, metaconceptual awareness of existing ideas, metaconceptual awareness of the use of initial and current ideas in different contexts, metaconceptual knowledge about the generalizability and applicability of scientific and own ideas.</td>
</tr>
</tbody>
</table>
students. In addition to the weekly meetings, the teacher and I talked about the teaching sequence and instructional activities for 10 to 15 minutes each day before or after the class period to ensure that instructional interventions were implemented in the way as intended.

Data Analysis

In this study, the data were collected from multiple sources by using various methods that were in harmony with the research questions. Two main sources of data existed: quantitative data (whole class’s pre-test, post-test and delayed test scores on the FCI), and (2) qualitative data (audio-recording of interviews, group-based activities, video-recordings of class discussion, and students’ journal writings). Depending on the nature of research questions and the data sources, two types of data analysis needed to be performed: quantitative data analysis and quantitative data analysis. Quantitative data analysis was carried out to investigate the effectiveness of metaconceptual teaching interventions on students’ conceptual understanding of force and motion concepts in comparison to traditional instruction and the durability of the impact of metaconceptual teaching interventions on their conceptual understanding about force and motion. Qualitative data analysis was done to describe focus students’ metaconceptual processes in relation to the change in their conceptual understanding.

Quantitative Data Analysis

In order to investigate the effectiveness of metaconceptual teaching interventions on students’ conceptual understanding and the durability of the impact of metaconceptual teaching interventions on students’ conceptual understanding of force and motion,
students in the experimental group were statistically compared to students in the control group in terms of their conceptual understanding assessed by post- and delayed FCI.

The mean scores obtained by students’ scores on the FCI administered prior to the instructional interventions show that experimental group (Mean$_{pre-FCI}=10.00$) students outperformed students in the control group (Mean$_{pre-FCI}=8.74$). The differences between experimental and control groups in terms of their pre-instructional conceptual understanding of the force and motion would be confounded with the result of inferential statistics if the differences in students’ pre-instructional conceptual understanding was not controlled. In order to attribute any significant difference in the experimental and control groups to the effect of instructional treatments, students’ pre-instructional conceptual understanding needed to be statistically controlled. Analysis of covariance (ANCOVA) is a useful technique for statistically equating groups on one or more covariates. In other words, ANCOVA is used to adjust the mean differences in the dependent variable to the level that would be expected if group covariate means were equal from the start (Huitema, 1980).

ANCOVA was generated to adjust the effect of instructional treatments on students’ conceptual understanding for differences in students’ conceptual understanding prior to the instructional interventions. In other words, in order to statistically control the initial differences between the experimental and control groups, students’ pre-test scores on the FCI were used as the covariate. ANCOVA was generated twice in this study: (a) to statistically compare experimental and control groups in terms of students’ post-FCI scores, and (b) to statistically compare experimental and control groups in terms of
students’ delayed-FCI scores. An SPSS statistical program was used to generate ANCOVA. The following null hypotheses were tested by using ANCOVA:

1. There is no significant mean difference between students exposed to metaconceptual teaching interventions and those exposed to traditional instruction on their post-FCI scores when their pre-FCI scores are statistically controlled.

Ho: \( \mu_{\text{experimental (post-FCI) (adj)}} = \mu_{\text{control (post-FCI) (adj)}} \)

2. There is no significant mean difference between students exposed to metaconceptual teaching interventions and those exposed to traditional instruction on their delayed-FCI scores when their pre-FCI scores are statistically controlled.

Ho: \( \mu_{\text{experimental (delayed-FCI) (adj)}} = \mu_{\text{control (delayed-FCI) (adj)}} \)

In addition to testing these hypotheses, descriptive statistics, along with a graph that depicts the mean scores of experimental and control groups on pre-FCI, post-FCI and delayed-FCI, were produced. Effect size values were also calculated.

**Qualitative Data Analysis**

Qualitative data in this study involved the data collected from various sources including interviews, audio-recordings of group-based activities, video-recordings of class discussions, and journal writings of the students in the experimental group. In this study, only the data relevant to the three students were transcribed and analyzed. Among the three students, data of the two students were used for intensive case studies. Data of all three students were used to describe the trends in each type of metaconceptual process. In analyzing the data, the major analytical unit was each individual student.
Qualitative data analysis was performed to provide answer to the third research question: what is the nature of the metaconceptual knowledge and processes students engage in during the metaconceptual teaching practices in relation to their conceptual understanding of force and motion? The focus of this question is not only to identify and describe the types of metaconceptual processes, but also to portray the changes in students’ force and motion ideas and their metaconceptual processes related to those ideas. Therefore, the data analysis entailed the identification and description of two main aspects of students’ thinking: (a) the change in students’ conceptual understanding about force and motion before and after the instructional interventions; and (b) the nature of students’ metaconceptual processes that they engage in during the instructional interventions.

Analysis of Students’ Conceptual Understanding of Force and Motion

Students’ ideas about force and motion were identified by using students’ interviews about force and motion. In order to explore the changes in students’ conceptual understanding about force and motion, students’ pre-instructional and post-instructional science ideas were first identified and then the differences between them were documented. Students’ pre- and post-instructional ideas about force and motion were identified by using the pre-and post-instructional interview transcripts. In analyzing data, the focus was the individual student. The data were analyzed to describe the change in each individual student’s ideas about force and motion, rather than identifying the types of alternative ideas that a group of students held. For each of the pre- and post-instructional interviews about students’ science ideas, transcripts were searched for
segments that exemplified two dimensions: (a) students’ ideas about force and motion, and (b) compatibility of students’ ideas with scientists’ ideas.

Analysis of students’ science ideas included three general steps. In the first step, all the interview transcripts were read to become familiar with the general features of the content of students’ ideas. Annotated comments were added to segments as the transcripts were read. Annotated comments included remarks about the content of students’ ideas, and characteristics of the context in which ideas were presented by the student (e.g., there exist forces in the opposite direction of objects’ motion).

In the second step, segments of the transcripts were coded in terms of the content of science ideas and the agreement between those ideas and accepted scientific view. As stated in Chapter 2, there exists a considerable amount of research literature that documented the types of students’ ideas of force and motion (Clement, 1982, 1983; Halloun & Hestenes, 1985b; McCloskey, 1983). Coding categories for students’ science ideas were developed by searching segments that exemplified conceptions described in the literature (e.g., force implies motion, constant speed results from constant force, an object stops when its force is used up) and also other ideas emerged in the transcripts (e.g., inertia has an amount, inertia is related with the speed of the object, action-reaction forces cancel each other out). After each segment was coded in terms of the content of students’ ideas, the same segment was categorized as either a Newtonian or non-Newtonian idea. Having segments assigned to the above-stated dimensions, they were subcategorized into emerging topic areas, such as definition of force, friction, circular motion, forces acting on objects at rest, one dimensional motion, two-dimensional
motion, forces acting on objects in the absence of opposite forces, and forces acting on objects in the presence of opposite forces.

In the third step, all segments assigned into coding categories developed in the second step were read. I went over the data back and forth as I compared and contrasted segments assigned to the same categories. If a segment applied to more than one category of students’ science ideas, it was placed into both. When necessary the segments were reassigned into a more appropriate coding category.

Analysis of the Nature of Students’ Metaconceptual Processes

Relevant segments of students’ journal entries, transcripts of the audio-recordings of group-based activities, video-recordings of class discussions, and interviews about concept learning were used to identify the nature of metacognitive processes that students engaged in during the metaconceptual teaching interventions. Data analysis focused on seeking evidence for each of the three students’ engagement in metaconceptual processes. Before starting data analysis, data from all sources were organized in chronological order. The analysis proceeded through three steps.

Merriam (1998) described qualitative data analysis as a complex process “that involves moving back and forth between concrete bits of data and abstract concepts, between inductive and deductive reasoning, between description and interpretation” (p. 178). In the first step of analysis, I went over the data back and forth to search for individual student’s statements that exemplified the following broad metaconceptual coding categories: (a) metaconceptual awareness; (b) metaconceptual monitoring; and (c) metaconceptual evaluation. The main categories were derived from the taxonomical
differences in metacognitive processes presented in Chapter 2. Segments that were related to students’ recognition of their existing knowledge were assigned to metaconceptual awareness. Metaconceptual monitoring category included any statements related to processes that generated information about learners’ thinking processes and cognitive state as they came across new information. Students’ statements that involved their judgmental decisions about the validity of ideas and their comments about the usefulness and plausibility of ideas along with their justifications were placed into the metaconceptual evaluation category. As segments were assigned to the above-stated general categories, annotated comments were added regarding the scientific content of the process, differences among processes assigned to the same category, and the context of the instructional activities.

In the second step of analysis, my aim was to develop subcategories within each level of the above-stated general metaconceptual processes. I compared one incident to another within each of the general categories and made a list of terms and comments. As I developed the subcategories, I compared one set of incidents assigned to a subcategory to other sets of incidents placed into another subcategory of metaconceptual awareness, monitoring, and evaluation.

In the third step, after I generated a list of subcategories, I went over the data several times to find segments that exemplified the list of metaconceptual processes in the coding scheme. A segment that included the characteristics of more than one type of metaconceptual processes was placed into both categories. In this step, the segments coded in terms of the types of metaconceptual processes were also categorized in terms of the science content. For example, for a segment coded as metaconceptual awareness of
existing ideas, a second coding category depicting the content of the idea was created. After multiple iterations of this analysis scheme, segments coded in terms of the types of metaconceptual processes and the science content were sorted in terms of metaconceptual processes to look for the trends in each type of metaconceptual processes.

Assigning segments of data to appropriate coding categories sometimes required a high degree of inference. After placing students statements into coding categories, I went back and forth between the context of the instructional activities and students’ statements. In this study, data were collected from multiple sources. When there was ambiguity in one statement, I looked for other segments and incidents in the whole corpus of data that pointed out the same or similar assertions.

Validity Issues of the Study

Internal Validity of the Experimental Study

Internal validity means that observed differences on the dependent variable (FCI scores) are directly related to the independent variable (treatment), and not related to some other unintended variables (Fraenkel & Wallen, 1996). Fraenkel and Wallen listed the threats to internal validity as subject characteristics, mortality, location, instrument decay, data collector characteristics, data collector bias, testing, history, maturation, attitude of subjects, regression, and implementers effect. The ways how to control each of these threats to internal validity of the present study are discussed as follows:

Subject Characteristics

Although students were assigned randomly to experimental and control groups, there were differences between experimental and control groups in their conceptual
understanding that they had prior to the instructional interventions. In order to control the effect of this difference on students’ post- and delayed FCI scores, ANCOVA was used. Through using ANCOVA, students’ post- and delayed-FCI scores were adjusted for the differences between experimental and control groups in their pre-instructional FCI scores. In doing this, it was ensured that the difference between control and experiment groups in their post-instructional conceptual understanding could not be attributed to the difference between control and experiment groups in their pre-instructional conceptual understanding.

*Mortality*

On the day the post-FCI was administered, two students from the control group and one student from the experimental group were absent. When the delayed-FCI was administered, one student from each group was absent. The percentage of students who did not take these tests was not high. Students who were not present on the day the test were administered were dropped from statistical analyses. Before the administration of the tests, students did not know that they were going to be tested. Therefore, their absenteeism could not be related to low self-efficacy about conceptual understanding of force and motion. Students who were not present on the days the FCI was administered reported that they did not attend class either due to sickness or an activity required by the school. Therefore, it can be said with confidence that the loss of these subjects did not favor any particular groups.
Location

In this study, all testing and treatments took place in a regular classroom during scheduled course periods for both the control and the experimental groups. Since the testing and treatments took place in the same classroom, there were no differences in terms of physical arrangements.

Maturation

Participants of this study consist of eleventh and twelfth grade students. Maturational difference between students in these grades is not high. Moreover, this study is not a longitudinal research and took only eight weeks. Therefore, maturation is not a threat for this study.

Instrument Decay

The FCI used in this study does not permit different interpretations of the scores because it is a multiple-choice test. Each student’s answer sheet was scored twice by the researcher.

Data Collector Characteristics and Data Collector Bias

These threats to internal validity were controlled by using standard procedures in both groups during the administration of the FCI. The researcher was present the whole time during the implementation of the FCI. Equal amounts of time were given to both groups to complete the tests. The directions of the instruments were read to students and necessary explanations were given by the researcher.
Testing

Administrating the FCI prior to the instructional interventions might affect students’ performance on post- and delayed-FCI. However, there was an almost ten-week period between the administration of pre-and post-FCI and a nine-week period between the administration of post- and delayed-FCI. The duration between the implementations of the test reduced the effect of pre-test on post-and delayed-test. Moreover, pre-test was given to both groups. It was assumed that the administration of the pre-test affect both groups equally.

History

The tests were administered in both groups on the same day. No extraneous events that might affect the dependent variable were reported.

Attitude of Subject

The way in which participants view a study and their participation in it can create a threat to internal validity. Recipients of an experimental treatment may perform better because of the novelty of the treatment rather than because of the specific nature of the treatment (Fraenkel & Wallen, 1996). In this study, various group-based activities and journal writing were used in the experimental group. Journal writing is not a totally novel activity for the experimental group. The teacher was using journal writing activity and group work (while performing laboratory experiments) as part of his regular instruction prior to the instructional interventions. However, the purpose and the content of these activities were new and could not have been controlled in any ways due to the nature of this study.
**Implementation**

In this study, the same teacher instructed both the experimental and the control groups. The teacher had more than fifteen-year science teaching experience and was familiar with conceptual change and metacognition literature. Prior to the instructional interventions, the teacher was trained to implement the instructional treatment in both groups in the intended way through discussions and making him part of the development of instructional activities. During the instructional interventions, the teacher and the researcher met on a regular basis to discuss the ways each instructional activity was implemented and science knowledge was introduced in both groups. He provided both groups with same scientific content. The scientific knowledge produced during group-based activities was made available to the students of the control group through lecturing. Both classes were observed by the researcher to ensure that the teacher implemented the instructional interventions in the intended ways.

**Trustworthiness of the Qualitative Study**

Trustworthiness is an important concern for analyzing qualitative data (Lincoln & Guba, 1985; Merriam, 1998). According to Lincoln and Guba, the basic question addressed by the notion of trustworthiness is: "How can an inquirer persuade his or her audiences that the research findings of an inquiry are worth paying attention to?" (1985, p. 290). There are several criterion areas for establishing trustworthiness: credibility, transferability, dependability, and confirmability (Lincoln & Guba, 1985).

In the context of this study, credibility can be translated as whether my accounts about the nature of students’ metaconceptual processes and their conceptual understanding of force and motion matched what students actually demonstrated. In order
to enhance the credibility of my accounts for this study, I used three different techniques including member checking, calculating inter-coder reliability (percent agreement), and prolonged engagement.

Member checking technique was used throughout the interviews conducted to assess students’ science ideas and ideas about their concept learning. During the interview sessions, I checked with the participants whether my understanding of their verbal comments was parallel with what they actually meant. Whenever there was a conflict, the participants were given the opportunity to further clarify their ideas.

One of the techniques for addressing credibility includes making segments of the raw data available for others to analyze (Lincoln & Guba, 1985). Although this technique does not ensure validity, when it is not established properly, the data and interpretations of the data cannot be considered as valid. I asked a colleague who is outside the context of the study but familiar with the nature of this study and has interest in metacognition and conceptual change to code 10% of the transcripts independently by using the developed coding scheme. 10% percent of the transcript was randomly chosen from interview data and a collection of data from other sources. The percentage of agreement for coded segments of the transcripts was calculated for interview data, which was used to assess students’ conceptual understanding, and data from other sources, which was used to describe the nature of students’ metaconceptual processes. For interview data, percent agreement was calculated for each level of the coding categories (the content of students’ ideas and compatibility of students’ ideas with scientific views). Inter-coder reliability (percent agreement) for the content of students’ ideas was calculated as 96.10%, and for the compatibility of their ideas with scientific views as 100%. Percent
agreement for metaconceptual processes was found as 86.71%. Considering that coefficients of .80 or greater are acceptable (Neuendorf, 2002), an acceptable level of reliability was achieved for coding segments in terms of the metaconceptual processes, science ideas and compatibility of the students’ ideas with scientific views. To resolve the discrepancies, the segments were reexamined and a consensus was reached on the conflicted codes.

Prolonged engagement was achieved by being present in the research site for an extended period of time. In order to establish prolonged engagement, I started observing both of the classrooms seven weeks before instructional interventions began. Throughout that time, I was able to get acquainted with the research site, classroom context and participants of the study. During the eight-week instructional interventions, I attended all class sessions in both groups to observe participants of the study as they participated in instructional activities.

Thick description of the events, activities, and participants needs to be included in naturalistic inquiry to establish the transferability of the findings (Lincoln and Guba, 1985). In order to enable others wanting to apply the findings of this study to their own research, thick description of the experiences, context of the research site, and the activities performed in classrooms will be provided.

Limitations of the Study

There are several limitations of this study. In this study, the aim of using metaconceptual teaching interventions was to facilitate students’ engagement in metaconceptual processes. The effectiveness of metaconceptual teaching practices was
investigated by comparing their effect on students’ conceptual understanding to that of traditional instruction. Moreover, this study also aimed at describing the nature of metaconceptual processes. Metaconceptual processes by definition are internal processes. In this study, students’ metaconceptual processes described were limited to those made explicit by individual students. In other words, the types and the nature of metaconceptual processes were those derived from students’ written and verbal comments. The verbal statements and written documents may not reflect all the metaconceptual processes that students engaged in. However, they may provide a significant contribution in describing those processes.

Use of metaconceptual teaching interventions to facilitate metaconceptual processes in the experimental group does not necessarily mean that students in the control group did not engage in any metaconceptual processes. Therefore, any difference that was found in the experimental and control groups after the instructional treatments could not be attributed to the lack of control group students’ engagement in metaconceptual processes, but rather the results should be attributed to the effect of facilitation of metaconceptual processes.

In this study, in order to facilitate metaconceptual processes of students in the experimental group, group-based activities including group discussions, group debates and poster drawing were used. In the control group, on the other hand, students worked in groups only when they performed laboratory experiments. In this research, the effect of the cooperative work on students’ conceptual understanding could not be isolated from the effect of facilitation of metaconceptual processes. However, it should be kept in mind that the group-based activities did not aim to promote any kind of skills and processes,
but rather metaconceptual awareness and evaluation. Scientific knowledge covered in
group-based tasks was made available to students in the control group through lecturing.

This study was conducted with 45 participants. The sample size represents a very
small portion of the student population. Thus, small sample size limits the
generalizability of the findings of this study to a large student population.
CHAPTER 4
ANALYSIS AND RESULTS OF DATA

Overview of the Chapter

This chapter describes the results of the analysis of data collected during this research to answer the questions stated in Chapter 1, which are:

4. What are the effects of metaconceptual teaching practices on students’ understanding of force and motion concepts?

5. What are the effects of metaconceptual teaching practices on the durability of students’ understanding of force and motion concepts?

6. What is the nature of the metaconceptual processes students engage in during the metaconceptual teaching practices in relation to their conceptual understanding of force and motion?

Considering the nature of the above research questions and the data analyzed to answer these research questions, this chapter is divided into two major sections. The first section is devoted to answering research Questions 1 and 2. It describes the results of the quantitative data analysis generated by using Force Concept Inventory (FCI) scores of students in the experimental and control groups. This section involves an explanation of both descriptive statistics and inferential statistics used to compare the FCI scores of experimental and control groups.
The second section addresses the third research question, portraying the nature of students’ metaconceptual processes in relation to the change in their ideas. Data selected to answer this research question are taken from multiple data sources, including interviews, classroom and group discussions, journals, and students’ dialogue as they drew posters. This section consists of two parts. In the first part, an in-depth analysis of the case studies of two students (David and Lisa) selected from the experimental group is presented. In doing so, the types and science content of metaconceptual processes that are related their science ideas identified prior to and following the instructional interventions are portrayed. The second part of this section focuses on the description of the nature of each type of metaconceptual process, along with the trends, if any, observed within them. The examples provided for each type of metaconceptual process are taken from the analysis of data collected from three students, namely, David, Lisa, and Kelsey.

Questions 1 and 2: Effectiveness of the Metaconceptual Teaching on Students’ Conceptual Understanding

This section describes the results of the quantitative data analysis generated to investigate the effectiveness of the metaconceptual teaching interventions on students’ conceptual understanding following and nine weeks after the instructional interventions ended. In this research, the effectiveness of the metaconceptual teaching interventions is examined by comparing it with traditional instruction. To that end, conceptual understanding of students in the experimental group is statistically compared with the conceptual understanding of the students in the control group.
In this study, students’ conceptual understanding of force and motion concepts was measured by their responses to the FCI, which is a multiple-choice test developed to probe students’ commonsense ideas about force and motion concepts. Since each test item involves one correct option and four distracters that specifically address alternative ideas, the higher the scores students have for the FCI, the more scientifically accepted concepts they possess and consequently the better conceptual understanding they have.

This section is further divided into three subsections according to the types of analysis and research question answered. In the first subsection, descriptive statistics, including means and standard deviations are provided for pre-, post-, and delayed-FCI across experimental and control groups. In the second subsection, with the aim of answering the first research question, the results of ANCOVA generated to compare experimental and control group on post-FCI are described. In order to respond the second research question, the third subsection is devoted to the results of ANCOVA generated to compare delayed-conceptual understanding of experimental and control groups.

Descriptive Statistics

This section portrays the descriptive statistics in the form of mean and standard deviations of the experimental and control groups’ FCI scores and describes the trends in the mean scores of experimental and control groups. The means and standard deviations of experimental and control group students’ scores on the FCI are presented in Table 4.1. Trends in the FCI scores of experimental and control groups are also seen visually in Figure 4.1.
<table>
<thead>
<tr>
<th>Groups</th>
<th>N</th>
<th>Mean</th>
<th>St.Dev.</th>
<th>N</th>
<th>Mean</th>
<th>St.Dev.</th>
<th>N</th>
<th>Mean</th>
<th>St.Dev.</th>
</tr>
</thead>
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<tr>
<td>Experimental</td>
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<td>10.00</td>
<td>3.28</td>
<td>21</td>
<td>19.19</td>
<td>5.75</td>
<td>21</td>
<td>19.14</td>
<td>6.03</td>
</tr>
<tr>
<td>Control</td>
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<td>8.74</td>
<td>3.31</td>
<td>21</td>
<td>13.90</td>
<td>4.56</td>
<td>22</td>
<td>12.64</td>
<td>4.77</td>
</tr>
</tbody>
</table>

Table 4.1: Means and standard deviations of students’ scores on pre- post- and delayed-tests.

As seen in Table 4.1, prior to the instructional interventions, there was a slight mean difference between experimental (Mean_{pre-exp}=10.00) and control groups Mean_{pre-cont}=8.74) on pre-FCI scores. The results presented in Table 4.1 and Figure 4.1 show that the scores achieved by students of the experimental group were consistently higher than those obtained by their counterparts of the control group, both on the post- and delayed-FCI. Although both groups showed an increase from pre-FCI to post-FCI, the overall mean difference between pre- and post-FCI was greater in the experimental group. In both groups, there was found a slight descending tendency in the overall performance over the nine-week period from the administration of post-FCI to delayed-FCI. However, as seen in Figure 4.1 the overall mean scores on delayed-FCI of the experimental group (Mean_{delayed-exp}=19.14) did not drop to the level of the overall mean scores of the control group (Mean_{delayed-cont}=12.64). In other words, students in the experimental group maintained their better understanding after a nine-week period. The decrease in students’ scores from post-FCI to delayed-FCI was slightly greater in the control group (from...
Inferential Statistics with Post-FCI Scores

This section describes the result of ANCOVA generated to compare experimental and control groups’ mean scores on post-FCI administered following the instructional interventions. In doing so, it is aimed at answering research question one: What are the
 effects of metaconceptual teaching practices on students’ understanding of force and motion concepts? The results of ANCOVA generated by using students’ post-FCI scores as the dependent variable and group (experimental group vs. control group) are presented in Table 4.2. Students’ pre-FCI scores were used as a covariate to statistically control the initial differences in experimental and control groups.

As Table 4.2 shows, ANCOVA resulted in significant F values for pre-FCI (F=27.17, p<.05) and for post-FCI (F=11.18, p< .05). The significant F value for pre-FCI shows that there was a significant mean difference between experimental and control groups prior to the instructional interventions and students’ scores on post-FCI were adjusted for this difference. The significant F value generated for post-FCI indicates that there was a significant mean difference between experimental and control groups in their post-instructional understanding when the significant differences in students’ pre-FCI scores were statistically controlled. In other words, when students’ post-FCI scores were

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
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<td>Pre-FCI</td>
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<td>442.13</td>
<td>27.16*</td>
<td>.000</td>
</tr>
<tr>
<td>Group</td>
<td>182.04</td>
<td>1</td>
<td>182.04</td>
<td>11.18*</td>
<td>.002</td>
</tr>
<tr>
<td>Error</td>
<td>634.91</td>
<td>39</td>
<td>16.28</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adjusted Total</td>
<td>1370.41</td>
<td>41</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*p< .05

Table 4.2: Results of ANCOVA for post-FCI.
adjusted for the differences in experimental and control group students’ pre-FCI scores, students in the experimental group significantly outperformed students in the control group in terms of their conceptual understanding measured by post-FCI. This result implies that students in the experimental group more successfully accommodated scientific ideas about force and motion compared to students in the control group. It can be claimed with confidence that metaconceptual teaching interventions had a significant positive impact on students’ conceptual understanding compared to the teachers’ traditional instruction.

Effect size is the proportional amount of the total variance that is attributed to the experimental treatments and is not affected by the sample size (Keppel, 1991). In other words, it is the proportion of variation explained by the treatment manipulation. Partial eta squared was found to be 0.22, indicating a large effect size according to Cohen (1988). It means that 22% of the variance on students’ post-FCI scores was explained by the differences in the instructional treatments.

*Inferential Statistics with Delayed-FCI Scores*

This section describes the result of ANCOVA generated to compare experimental and control groups’ mean scores on delayed-FCI administered nine weeks after the instructional interventions. This analysis aims to answer research question two: What are the effects of metaconceptual teaching practices on the durability of students’ understanding of force and motion concepts? The results of ANCOVA generated by using students’ delayed-FCI scores are presented in Table 4.3. Similar to the previous
Table 4.3: Results of ANCOVA for delayed-FCI.

<table>
<thead>
<tr>
<th>Source</th>
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<th>df</th>
<th>MS</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-FCI</td>
<td>267.25</td>
<td>1</td>
<td>267.25</td>
<td>11.39*</td>
<td>.002</td>
</tr>
<tr>
<td>Group</td>
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<td>265.81</td>
<td>11.33*</td>
<td>.002</td>
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<tr>
<td>Error</td>
<td>938.41</td>
<td>40</td>
<td>23.46</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adjusted Total</td>
<td>1660.51</td>
<td>42</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*p< .05

The results of ANCOVA presented in Table 4.3 show that there was a significant mean difference (F=11.33, p< .05) between experimental and control groups in students’ conceptual understanding measured by delayed-FCI. When the differences in students’ conceptual understanding before the instructional interventions were statistically controlled, students in the experimental group significantly outperformed those in the control group even after a nine week period. In other words, the experimental group students’ FCI scores did not drop to the level of the control group students’ FCI scores nine weeks after the instructional interventions ended, but rather, the experimental group students maintained their better conceptual understanding. This result indicates that metaconceptual teaching interventions not only had significantly more positive impact
following the instructional interventions but the positive difference in favor of the experimental group lasted for nine weeks.

Partial eta squared, which was calculated to be 0.22, indicates that the use of metaconceptual teaching interventions had a large effect size on students’ delayed conceptual understanding and explained 22% of the variance on the delayed-FCI.

Question 3: Nature of Students’ Metaconceptual Processes

This section answers research question three: What is the nature of the metaconceptual knowledge and processes students engage in during the metaconceptual teaching practices in relation to their conceptual understanding of force and motion? In answering this research question, the intention of this study was to (a) distinguish and categorize different types of metaconceptual processes, (b) describe the trends in each metaconceptual process, and (c) portray the nature and the content of the metaconceptual processes that were related to students’ science ideas that changed (or did not change) following the metaconceptual instructional interventions. To that end, this research question was answered in two steps.

In the first step, a detailed analysis of two case studies (David and Lisa’s case) was provided to describe the range, type and content of the metaconceptual processes that students engaged in as they participated in metaconceptual teaching activities. As the third research question above indicates, the focus of this question is not only to identify and describe the types of metaconceptual processes, but also to portray the science ideas that students held prior to and following the instructional interventions and describe students’ metaconceptual processes about those ideas. In doing so, it was not the
intention of this study to explore a causal, straightforward and one-to-one relationship between the observed changes in students’ ideas and any particular metaconceptual process. Although metaconceptual processes are an integral component of the change in students’ ideas (Hennessey, 1999, 2003), it is beyond the limits of this study to find direct, one-to-one evidence for this relationship, as both conceptual change and metaconceptual processes are complex and multi-faceted. Instead, the intention of the case studies is to identify students’ ideas prior to and after the instructional interventions, summarize the changes in their ideas, and describe the metaconceptual processes observed about those ideas.

Throughout the instructional interventions, several physics topics (e.g., definition of force, Newton’s First Law, Newton’s Second Law, Newton’s Third Law, friction, projectile motion, gravity, and circular motion) were addressed. A complete description of the content of each physics concept that David and Lisa held prior to and following the instruction and all of the metaconceptual processes related to those concepts would be an enormous task and is beyond the scope of this study. Instead, for each case study, force and one-dimensional motion is selected as a content area to track students’ ideas before and after the instruction and to describe their metaconceptual processes related to those ideas. Within this content area, definition of force, relationship between force and motion, and Newton’s First Law are examined. This content area is representative enough to explain the types and range of the metaconceptual processes encountered by the students during the metaconceptual teaching practices.
In the second step, the nature of and the trends observed in each type of metaconceptual process are described, along with a variety of examples drawn from all content areas covered in this study. In portraying each type of metaconceptual process, data collected from Kelsey were used, along with data collected from David and Lisa to add variety to the examples used to explain a particular metaconceptual process.

Data used to respond to the third question were taken from students’ interviews, class and group discussions, group debates, journal writings, and students’ dialogue as they drew and presented posters.

**Overview of the Types of Metaconceptual Processes**

In order to understand the case studies, it is necessary to provide a preview of the types of metaconceptual processes before explaining them in detail for each case student across different conceptual topics. At this point, my aim is not to provide evidence for each metaconceptual category, but rather to provide a brief description of qualitatively different metaconceptual processes derived from the preliminary analysis of the transcripts. The types of metaconceptual processes are reexamined at the end of the case studies, along with extensive examples of each category.

There are three main types of metaconceptual processes found in the data from the three students in the case study: (a) metaconceptual awareness, (b) metaconceptual monitoring, and (c) metaconceptual evaluation. Within each type of metaconceptual process, several subcategories were found, based on the qualitative differences among them. A brief description of the three main types of metaconceptual processes is provided below.
Metaconceptual Awareness

Metaconceptual awareness is a process in which the learner explicitly refers to her/his personal stock of information including current or past ideas regarding a concept, presuppositions, experiences, and contextual differences. Two categories of metaconceptual awareness were found in the data: first-order metaconceptual awareness and second-order metaconceptual awareness.

A. First-order Metaconceptual Awareness: First-order metaconceptual awareness is one’s explicit recognition of or reflection on existing concepts, generative or stored representations of the physical world, and elements of conceptual ecology. As learners engage in first-order metaconceptual awareness, they may also refer to a conceptual entity that is missing in their existing conceptual structure. Within the category of first-order metaconceptual awareness, five subcategories were derived from the data.

1) First-Order Metaconceptual Awareness of Mental Models and Ideas/Conceptions: Learners are considered to be metaconceptually aware of their ideas or mental models when they make explicit reference to their existing or generative ideas through talking, writing, or creating drawings about ideas (e.g., “I believe that force is necessary to keep an object moving.”).

2) First-Order Metaconceptual Awareness of Ontological Presuppositions: Learners are assumed to be metaconceptually aware of their ontological presuppositions when they explicitly reflect on their ontological beliefs about how and in what form entities exist in the world, or the properties that entities
may possess as a result of belonging to an ontologically distinct category (e.g., “I believe that force is an entity that is transferred from one object to another.”).

3) First-Order Metaconceptual Awareness of What You Do Not Know: As learners create mental representations to explain a physical phenomenon they may become aware that they do not know a conceptual entity or relations among entities. One’s realization that a conceptual variable is missing in his/her current explanation or one’s recognition that she/he does not know how that variable works in the given situation is a process characterized by this subcategory of first-order metaconceptual awareness (e.g., “I do not know whether momentum is considered as a force.”).

4) First-order Metaconceptual Awareness of Contextual Differences: Learners are assumed to become aware of the contextual differences when they explicitly make reference to contextual factors as they provide explanations for a physical phenomenon. Contextual factors may involve the variables about the characteristics of the environment (frictionless surface vs. surface with friction), or situated variables (object moving as a result of unbalanced forces vs. object moving as a result of balanced forces) (e.g., After I push an object and let it go, it slows down on a surface with friction but it continues to move at a constant speed on a frictionless surface.”).

5) First-Order Metaconceptual Awareness of Experiences: Learners who can verbally express their past experiences are assumed to be metaconceptually aware of experiences. While awareness of contextual differences involves
one’s general statements regarding the environmental and situated variables (e.g., motion of an object on a surface with friction and on frictionless surface), learners make reference to a particular experience when they engage in first-order metaconceptual awareness of past experiences (e.g., experience with hockey pucks).

B. Second-Order Metaconceptual Awareness: Second-order metaconceptual awareness refers to one’s reflection on the knowledge that is derived from monitoring of first-order metaconceptual awareness of his or her conceptual structure. In other words, it is a process in which the learners explicitly refer to their previous science concepts or other elements of their conceptual ecology that they had in the past. The same subcategories of first-order metaconceptual awareness apply to second-order metaconceptual awareness.

1) Second-Order Metaconceptual Awareness of Initial Ideas/ Mental Models: Learners engage in second-order metaconceptual awareness of initial ideas or mental models when they talk about ideas they held at an earlier time (e.g., “I used to believe that the force acting in the direction of objects motion had to be always greater than the force acting in the opposite direction.”).

2) Second-Order Metaconceptual Awareness of What You Did Not Know: In addition to awareness of ideas they held at an earlier time, learners may also have knowledge about what they did not know in the past, what variables were missing in their previous conceptual structure, or how a conceptual variable works in a situation (e.g., “When we discussed the situations as a
group I realized that I did not know in what ways friction plays a role in the objects’ motion.”).

3) **Second-Order Metaconceptual Awareness of Contextual Differences:** Second-order metaconceptual awareness of contextual differences is a process in which the learner reflects on her or his past use of concepts in different contexts (e.g., “I used to believe that the force in the direction of an object’s motion had to be greater no matter whether the object was moving at a constant speed or at increasing speed. I treated both situations in the same way.”).

4) **Second-Order Metaconceptual Awareness of Ontological Presuppositions:** Learners engage in second-order metaconceptual awareness of ontological beliefs when they refer to their previous ontological presupposition about the kinds of entities and the way they are categorized (e.g., “I initially believed that only animate objects could exert a force.”).

5) **Second-Order Awareness of Experiences:** Second-order awareness is a process in which learners think about how they interpreted their experiences in the past (e.g., “In the past when I saw that a heavy metal ball and plastic ball fell to ground at the same time, I thought that the same gravitational forces acted on them.”).

### Metaconceptual Monitoring

Metaconceptual monitoring processes are “online” and “in the moment” processes that generate information about an ongoing cognitive activity, thinking process, or one’s
present cognitive state. Metaconceptual monitoring entails controlling of one’s cognitive state when she or he comes across with a new conception. Five types of metaconceptual monitoring processes were found in the data.

1) *Monitoring of Understanding of an Idea:* Monitoring one’s understanding of an idea is a process in which learners comment on their comprehension of an idea (e.g., “I think I do not understand Newton’s Third Law. I know this because I cannot explain it to someone else.”).

2) *Monitoring Ideas/Information from Other People/Sources:* Monitoring other people’s ideas is a process in which learners make reference to the content of other people’s ideas. They may also recognize information from other sources such as books (e.g., “During the class discussion one of my friends said that force was not necessary for motion.”).

3) *Monitoring the Consistency Between New Idea and Existing Idea:* Learners engage in this process when they make comparisons between what they already know or think and the information that comes from other sources such as other students, books, or a teacher (e.g., “Some of my friends said that force does not act on the book after it lost contact with the hand. But I think force still acts on it even though a hand is not pushing it anymore.”).

4) *Monitoring the Consistency between Existing Idea and New Experience:* Learners who engage in this process compare their own ideas with what they observe or experience (e.g., “I think that heavier objects fall to Earth faster than light objects. However, during the demonstration I saw that heavy and light balls fall to ground at the same time.”).
5) Monitoring Change in Ideas: Monitoring the change in one’s ideas is a process in which the learner makes a comparison between what she or he initially knew and what her or his current ideas are (e.g., “I used to think that an object acquired a force after it was set in motion and that force kept it moving until it stopped. After our classroom discussion I changed my mind. I currently think that force is not transferred from the agent to the object, and force is not necessary to keep objects moving.”).

Metaconceptual Evaluation

In an attempt to learn a new conception, learners evaluate conceptions by making judgmental decisions about their existing ideas or new conceptions. Learners may engage in this evaluation process in different forms. Although the ways learner engage in metaconceptual evaluation may be different, the end product is an evaluation of the ability of competing conception to explain the physical phenomenon. Learners may metaconceptually evaluate concepts by:

1) making comments about the relative plausibility and usefulness of existing or new ideas. In doing so, learners may directly explain why an idea is attractive or believable to them. Learners may not always use terminology to talk about the plausibility of their ideas. They may also simply refer to the plausibility of an idea by stating the reason for why an idea is wrong and another is true. These processes require the learner to make comment “about” an idea (e.g., “I think that force is necessary for motion. During class discussion someone told me that an object might not necessarily move even though force acted on it.”)
This idea is attractive to me because when you push a heavy object like a car it does not move.”).

2) choosing an idea among different alternatives and defending why that idea works better than the other ones for the given situation (e.g., “I think alternative D is the best explanation for this situation. Because the book is not accelerating. If it were not D or if there were no upward force acting on the book it would accelerate in the downward direction.”).

The types of metaconceptual processes described above are presented in Table 4.

**General Comments on Case Studies**

Two case studies (David and Lisa’s case) are presented below. Each case study begins with brief personal information about the student’s academic background. Then, the student’s conceptual ideas prior to and after the instructional interventions are identified and the change in students’ ideas is summarized. Finally, metaconceptual processes related to student’s ideas regarding force and one-dimensional motion are described. It is worth noting that the aim of the sections devoted to the description of each student’s metaconceptual processes is not to categorize the types of metaconceptual processes, but rather to describe them, along with the content of student’s ideas, within the contexts of instructional activities. A summary of the categories of metaconceptual processes, along with examples from three students for each category, is presented at the end of the case studies.
Table 4.4: Types of metaconceptual processes.
Throughout the instructional activities, students provided extensive evidence of their ability to engage in qualitatively different types of metaconceptual processes ranging from awareness of their ideas to more sophisticated higher-order thought. Within the limits of this dissertation, it is not possible to describe every metaconceptual process students displayed. However, the examples given are representative enough to show the diversity of their metaconceptual processes and the content of their ideas. In the section devoted to the description of each student’s metaconceptual processes, students’ metaconceptual processes are examined within three main conceptual topics: definition of force, relationship between force and motion, and Newton’s First Law of Motion. Within each conceptual topic, students’ metaconceptual processes are described in a chronological order to give a sense how their ideas evolved as they engaged in those processes.

*David’s Case*

David is an eleventh grade student in the experimental group. He was chosen as one of the case students because he was one of the three students who took a physics course before the one in his study. In the summer prior to his enrollment in this physics course, David took a college level physics course in which he studied Newton’s Laws. He defined himself as a learner who wants to “understand not just how, but why.” He wants to study engineering at college. Out of the 30 questions on the FCI, David responded correctly to 13 items on the pre-FCI, 26 on the post-FCI administered immediately following the instruction, and 30 on the delayed-FCI administered nine weeks after the instruction.
David’s Pre-Instructional Ideas about Force and One-Dimensional Motion

Prior to the instructional interventions, David considered force as an entity that caused a change in an object from a certain state of being to another state. In the excerpt from a pre-instructional interview David said:

If something is exerting a force, then it is causing some other object, causing a change in some other object. If it's receiving a force, or if it's having a force acting on it, then it is changing from a frame of no change. From a period of time where it wasn't changing anymore, where it was a stationary object, or an object at a certain density, or certain whatever, then it starts to change from there. There has to be some sort of force to act upon it, to cause it to change.

Although David did not use the word acceleration in his statement, for him, the change caused by a force acting on an object could be from being stationary to starting to move. David could distinguish the outcome of force from other various kinds of motion. In the following quote, he directly stated that force caused objects to accelerate.

Nejla: What does the word 'force' mean to you?
David: I don't know if it's necessarily motion, maybe some kind of impact upon another object.
Nejla: What kind of impact?
David: I mean not necessarily physically something causing another object to move or change in some way. Like in the star, the closer you go to the middle the more compact the gases are because there's the force of the gravity of all of the other gas molecules acting on them. So it could be something like that or it could be something causing, you know, if you push a pencil across the desk, the force is your finger on the pencil that's causing it to move.
Nejla: What kind of motion are you talking about?
David: You mean like direction?
Nejla: Is it for example speeding up, constant motion, or slowing down?
David: Probably accelerating.

Although David’s definition of force as being an entity that causes objects to accelerate is scientifically accurate within the contexts he provided, he did not specify that it was the
unbalanced forces that were responsible for objects’ acceleration. In other words, he did not make a distinction between the outcome of unbalanced and balanced forces.

Having taken a physics course before, David was familiar with the concepts of momentum and inertia. However, his interpretations of these concepts were not consistent with the scientifically accepted idea that objects set in motion remain in motion. Although it is the natural tendency of the objects to keep moving or remain at rest, David considered inertia or momentum as entities that kept objects moving in the direction of their motion. When asked the forces acting on a ball that was thrown up, he used the words inertia, momentum and force interchangeably to refer to an acquired entity that kept the ball moving upward.

Nejla: Could you describe what happens when I throw this ball up, in terms of its speed and forces, if any, acting on the ball?
David: As far as I know you’re causing the force here at point A just as it starts to rise here, and then you raise it to a certain speed depending on how hard you throw it up, and gravity is a constant force – it’s always acting on the ball, and as it rises into the air it slows down because you’re no longer applying force to it and gravity is still force until it reaches a point where gravity and whatever momentum or inertia it had from your force are equal so then neither one of them is pushing the ball anywhere. And at that point [on the way down] gravity has begin to overpower the force of the ball and the momentum and on the way down that’s what it does. It doesn’t have any, it [gravity] now becomes greater than the force, the inertia of the ball which causes the ball to move downwards at an ever increasing speed because again the momentum or inertia or whatever is carrying the ball upward it’s decreasing even further. So as it decreases, as the distance between gravity and the ball increases, the ball moves faster and faster downwards.

Nejla: You say at the peak of its travel you said that gravity is equal to something.
David: It is equal to momentum or inertia
Nejla: Is it a force?
David: This is the thing. I’m always uncertain about it. I don’t think any force is acting on the ball as it’s traveling through the air other than gravity because I think what’s carrying it through is momentum or its inertia whatever it is …
Nejla: And you said that it was equal to?
David: Yeah and at that point it’s equal to gravity which, it’s like if you have one pound of something acting against a pound of something else then they’re not going to move, they’re both exerting the same amount of force.
Nejla: Could you compare the forces acting on the ball as it travels up in the air?
David: While it travels up the force, the momentum, or the inertia the ball had to overpower gravity at least for a little bit of time to be able to move up against that force. So I think I’m going to say at least while it’s moving up it’s overpowering gravity.

The above excerpt from the one-to-one interview provides evidence for David’s belief that the ball (which was set in motion by the applied force) acquired momentum, or inertia that either overpowered gravity or was overcome by the gravity, depending on its position. Although he was not sure whether momentum or inertia was considered as a force, for him, momentum or inertia was an entity, the amount of which could be compared to gravity. David thought that the amount of momentum or inertia overpowered gravity and decreased as the ball traveled up and became equal to gravity at the peak of the ball’s motion. For him, as the ball fell, the amount of momentum or inertia continued to dissipate and was overpowered by gravity. David assigned inertia to a scientifically inappropriate ontological category as he considered it as an entity that had an amount and dissipated as the object moved. Although David claimed that the only force acting on the ball was gravity, he used the words momentum, inertia and force interchangeably to refer something that kept the ball moving. In contrast to the Newtonian view of motion (motion needs no causal explanation), for David, the object had to have momentum or inertia to keep it moving.

Similarly, in a situation where there was no opposing force like friction or gravity, he unsurprisingly mentioned momentum or inertia when he was asked the forces acting on an object moving in space. However, his idea that the object would move forever at a
constant speed in the absence of an opposing force was consistent with Newton’s notion that objects in motion remain in motion at a constant speed.

Nejla: Suppose that I throw the same ball in the space where there are no other planets and no gravity what would happen if I throw this ball up?
David: The force here, it moves through space, there’s nothing to slow it down so there’s obviously no gravity if there’s no planets around and it would probably keep moving at a constant speed. I mean it’s going to achieve this constant speed from the force you exerted on it and it will keep moving at a constant speed probably forever because there’s no gravity to act upon it, there aren’t any planets around to slow it down so it …
Nejla: Are there any forces acting on the ball while it travels?
David: I’m going to say no, again it’s just the momentum or the inertia or whatever it is. It just doesn’t seem to make sense that there’s still a force acting on it when you only toss the ball here and it travels, I mean it could travel 100,000 miles away from here.

Throughout the pre-instructional interview, David displayed evidence for his alternative idea regarding the direction of the forces and the direction of the motion. He believed that “the direction that the object moves caused by the force depends on where the force is coming from, where the force is being enacted on.” David’s idea that the direction of force dictates the direction of the motion of the object was particularly seen in his explanations for situations where there were more than one force acting on an object. For those situations, he held the idea that the bigger force determines the direction of the object’s movement. For example, for David, on a falling ball the force acting downwards had to be greater than the force acting upwards, otherwise the ball would not move in the downward direction.

Nejla: I didn't quite understand your answer about the forces acting on each ball. Are they the same or are they different?
David: Well it looks like the two forces acting on the ball are gravity and the air resistance, and gravity is bigger than the air resistance because otherwise the balls wouldn't fall.
Throughout the pre-instructional interview, David showed no signs of having knowledge about the outcome of balanced forces. In situations where the object moves at a constant speed, David exhibited evidence for his idea that the amount of the force acting in the direction of the object’s motion had to be greater than of the opposing force. His response to the question regarding the amount of forces acting on a book moving at a constant speed clearly demonstrates his above-stated alternative idea.

David: When you push the book, the book reacts to your push, but I think the force you were acting upon the book is more than the force the book acts upon you because again it allows it to move but at the same time to keep it moving, you have to keep exerting that force on the book. You have to keep exerting a force above whatever the book is exerting upon you. So if you want to keep it moving at a constant speed you have to keep that same amount of force and you could push it just barely more than the book pushes back on you, if you, and right now I'm barely moving the book because it's just barely more than the force the book is exerting back on me, and if I want to keep it moving at that constant speed I could just keep pushing it, if you wanted to keep it moving at your constant speed you'd have to keep it pushing it more than I was pushing it. Keep a constant force that's more than just barely over the book's force."

Nejla: Do you say that the force that I should exert to keep the book move at a constant speed must be greater?

David: Yeah, and it doesn't have to change it just has to always be greater than what the book is exerting on you and if you want it to move at a constant speed then it has to be at the same amount greater. So, say the book would be exerting, I don't know, like negative three force on you, you have to push at least negative three point 000, however many zeroes, one - just over negative three, but if you want it to move, I mean if you exerted a force of four on this, then it's like a net gain of one, so you're still moving the book, if you wanted to keep it at that speed you'd have to exerting this force of four because then the four plus negative three would always equal one.

The excerpt above includes David’s explanation for a situation in which my finger was pushing a book across the table to keep it moving at a constant speed. David’s explanation not only shows his idea about the need for net forces in the direction of an object’s constant motion, it also indicates that he had alternative ideas regarding
Newton’s Third Law. Although he recognized the reaction force exerted by the book, he pictured it as a force to be canceled out by the action force from the finger. Having imagined the reaction force from the book as opposing the action force from the finger, David believed that the force exerted by the finger had to be greater than the force exerted by the book in order to keep the book moving at a constant speed. In other words, for David, there must be net forces in the direction of the motion even if the object moves at a constant speed.

Another alternative idea David expressed in the above excerpt was about his association of force with speed but not with acceleration. For David, in order to maintain an object’s constant speed, constant net force had to be exerted on it throughout its travel. To put it differently, one must continue to exert the same amount of net force on the object to keep it moving at a constant speed.

In summary, prior to the instructional interventions the following alternative ideas regarding force and one-dimensional motion were identified:

- Force causes objects to accelerate. However, he did not know that unbalanced forces caused objects to accelerate and balanced forces caused objects to move at a constant speed.
- Momentum or inertia that the object acquired keeps it moving. Therefore, moving is not a natural state of objects.
- Inertia is an entity, which has an amount.
- The amount of momentum or inertia decreases as objects move as a result of being overpowered by another force acting in the opposite direction.
- Direction of force dictates direction of motion.
• The amount of the force in the direction of the object’s motion must be greater than that of the opposing force.

• Continuous exertion of the same amount of net force causes objects to move at a constant speed.

David’s Post-Instructional Ideas about Force and One-Dimensional Motion

After the instructional interventions that facilitated students’ engagement in metaconceptual processes, David defined force as an interaction between objects that causes a change in the object’s current state of motion. The examples given by him involved objects that start moving, stopping, speeding up, or slowing down as a result of forces being exerted on them.

Nejla: How would you define force? What does force mean to you?
David: The way I see some object usually exerts it. I'm sure there is an exception but it is not. But it is the way two objects interact that can, you know, cause an object to stop or change its motion, accelerate, or decelerate.
Nejla: What do you exactly mean by change in motion?
David: I mean it is if the object is stopped or it might cause it to speed up in a certain direction. It might cause it to… If it is at a certain speed it might cause it to speed up it might cause it to slow down, it might cause it to stop. Whatever state of motion, you know, if it is in motion it might cause it to change its state of motion so its state of motion doesn't stay still.
Nejla: How do you know that force is acting on something?
David: If you see the object changes its state of motion. If it is moving, you know, if it stops all the sudden. Something had to be acting on it, it could be friction, it could be somebody hitting whatever the object is, you know, exerting a force to stop it. If it is something at rest it just starts moving. It could be a ball may be a wind causes it to start rolling. Something was interacting with it. Something was acting on it to change its motion.
Nejla: What do you exactly mean by interaction, you defined force as an interaction?
David: They are exerting influence on each other.
Nejla: What kind of influence?
David: An influence of motion or some kind of... They are influencing each other's motion but... I guess by interaction and influence they are exerting a change over the object and influence each other.
When David was asked how an object on a frictionless surface would move as it was being pushed continuously by a finger, he stated: “It would continue to accelerate. If you apply a constant force it would continue to accelerate. With an increasing force it would also accelerate.” Unlike his pre-instructional idea regarding the need for a constant force for keeping object at constant speed, David displayed evidence for his current idea that exertion of a constant force caused an object to accelerate.

Before the instructional interventions, David was unable to differentiate the outcome of balanced and unbalanced forces. He believed that when more than one force was acting on an object, the force in the direction of the object’s motion must be greater than the force acting in the opposite direction even if the object was moving at a constant speed. Below is a statement from David that illustrates how his ideas changed after the instructional interventions.

Nejla: What should I do to keep the book moving at a constant speed [across the table]?
David: All the way from point A to B, if you want to constant speed you have to apply a force equal to friction caused by the table.
Nejla: Could you generalize the statement to all situations whenever you apply a constant force, there is constant motion?
David: No. No. Frictionless ice rink will not have constant speed with constant force because there is no friction acting against it.
Nejla: What will happen if I exert a constant force?
David: The object will keep accelerating. The force will be unbalanced all the time. As long as there is a opposite force, normal force, frictional force if you exert a constant force the object will move at a constant speed if you exert a force that is equal to the opposite force.

In the above statement, David indicated that to keep the object moving at a constant speed, the amount of forces acting in the opposite directions had to be equal, otherwise the object would accelerate. It is clear from David’s statements that he acquired the
Newtonian view that balanced forces caused objects to move at a constant speed and
unbalanced forces caused objects to accelerate. For David, there is no need for net forces
in the direction of the object’s motion and continuous exertion of a constant force did not
always cause objects to move at a constant speed anymore.

During the post-instructional interview, David was reminded of his previous
conception concerning the need of a greater force in the direction of the object’s motion
at a constant speed. When he was asked the reason for his previous idea and why it did
not make sense to him anymore, he was able to apply his current Newtonian idea in a
different situation.

Nejla: Do you remember why you thought so in the previous interview?
David: Well I think it just made sense that, you know, in order something to move
you have to exert a force on it that is greater than what is keeping it. It just
made sense, you know, it seemed logical. It doesn't seem right that in
order something to move you, you have to put something on it that is
equal to what is already keeping it.
Nejla: Why is this idea not logical to you anymore?
David: I guess it would be if you are a really strong man you are holding a book
down on the table it will be like saying in order to lift it up you just have
to lift it up with the same force he is holding it down. You have to
overpower his strength. That is what you have to do to get it moving. After
that you just have to keep it equal to his force whatever it may be. I didn't
know about static friction or kinetic friction. It didn't make sense that in
order to keep it moving you have to equal what is keeping it from moving
it.

David’s explanation above shows that, for him, in order to start an object’s movement,
the amount of the force in the direction of the object’s motion had to be greater than the
force in the opposite direction and to keep the object moving, it was enough to exert a
force that was equal to the force in the opposite direction.

One of David’s pre-instructional ideas was that continuous exertion of a constant
force produces constant speed. When he was asked whether forces could cause objects to
move at a constant speed, he was able to correctly identify situations in which forces produced constant motion. He believed that in situations where there was friction the applied force had to “counteract” the resisting force, while in situations where there was no resisting force, like friction, there was no need for a force to keep the object moving at a constant speed.

David: Ok. Yeah I guess it can cause constant motion. It can. Yeah, that is what I said. If there is friction on the road you need a force to counteract it to have constant motion. If there is no friction there is nothing acting against it, there doesn't need to be a force acting on it to have constant motion.

Another idea held by David prior to the instructional interventions was his description of momentum or inertia as entities that kept object moving. Previously, he considered them as entities that had magnitude and dissipated as a result of being overcome by another force. David did not directly state that he considered inertia or momentum as a force. As he perceived momentum or inertia being overpowered by gravitational force, however, he assigned to these entities similar attributes possessed by force concept. After the instructional interventions, David showed hints of a change in his understanding of inertia and force. When he was asked the forces acting on a ball tossed up, he did not compare the amount of momentum or inertia with the amount of gravity as he did during the pre-instructional interview.

Nejla: I have this ball in my hand and I toss this ball up. Could you describe what is happening as the ball travels up, what is happening at the peak and as the ball moves down?
David: When you throw it up you exert an upward force on the ball. As soon as the ball leaves your hand I mean the whole time, gravity is exerting downward force on the ball. As soon as the ball leaves your hand, that force has nothing to counteract it. The force you exerted on the ball tossing it upwards was greater than gravity. Because there is nothing acting against gravity now it just accelerates downwards. So, on the way up the ball is slowing down. At the top the ball has no motion because the
gravity has accelerated it to zero. Immediately after that on the way down, gravity is still a downward acceleration. So it causes the downward speed to increase. So it is always exerting a downward force. The ball slowed down on the way up.

Nejla: Could you clarify what happens at the peak?
David: At this point at the top, gravity is still acting downward on the ball but the ball’s speed is zero. So it doesn’t move up or down at split second and then the gravity continues. It never stops, I mean the downward force [gravity]. And then the ball’s speed starts to increase. It moves downwards.

As his statements above indicate, David mentioned only gravity as a force acting on the ball throughout its travel. Unlike his response in the pre-instructional interview, David maintained that the speed of the ball at the peak of its trajectory was zero due to the ball’s deceleration by gravity rather than the equality of momentum or inertia and gravity.

During the post-instructional interview, David was reminded of his previous idea. The change in David’s ideas regarding his ability to differentiate inertia and force is more clearly seen in the excerpt below.

Nejla: In the first interview [pre-instructional interview] about the ball toss question you said that gravity and inertia or momentum are equal at the peak. Do you still agree with this idea?
David: No. First I don’t consider inertia as a force anymore. There is nothing really acting on the ball. If inertia were a force or if there were some force equal to gravity the ball or the space shuttle would continue moving at a constant speed upwards. Gravity wouldn't be overcoming it. The upward force would be equal to gravity. At the top or the peak I still think that gravity is constant, inertia is not a force. So, gravity acting downward on it does actually decrease the inertia. At the peak inertia itself is zero. Gravity is constant.

In his response above, David stated explicitly that he did not consider inertia as a force. He was also able to explain his reasoning for why his previous idea was not believable for him anymore. He maintained that if there were equal forces acting on the ball at the peak of its motion it would move at a constant speed in the upward direction. In other
words, for him, if inertia were a force, and equal to gravity, the ball would continue to
move at a constant speed. He based his reasoning on his knowledge about balanced
forces. Although David clearly said that inertia was not a force, in the last part of his
explanation, he argued that inertia was decreased by gravity as the ball moved upward
and became zero at the peak. Although he did not compare the amount of inertia with the
amount of force anymore, he considered it as an entity that had magnitude. For him, as
the speed of the object decreased, the amount of inertia decreased, and when the object
stopped, inertia became zero. Prior to the instructional interventions, for him, the ball
stopped because inertia was equal to gravity. It is obvious that, after the instructional
interventions, David associated inertia with the speed of the object.

Previously, for David, motion of the objects required an explanation. He thought
that inertia or momentum kept an object moving. After the instructional interventions,
however, he considered objects’ motion at a constant speed as a natural state of objects.
During the post-instructional interview, he was asked the forces acting in the horizontal
direction on a ball that fell off the table after it was pushed horizontally. The excerpt
below is a clear example for his idea concerning the natural tendency of objects to move.

Nejla: Are there any forces acting on the ball in the horizontal direction after it
leaves the table?
David: No.
Nejla: What keeps it moving?
David: What keeps it moving is that nothing is stopping it. There isn't any
friction. I'm sure air resistance will have something to do but I'm sure
there wasn't much air resistance that would slow it down. Normally there
is nothing acting backwards on the ball like friction on the table to slow it
down. In the air there is nothing to slow down its horizontal motion.
When David was asked what kept the object moving in the absence of a force acting on
it, he maintained that the object kept moving if there were no forces acting in the opposite
direction. David did not mention momentum or inertia or other entities as the cause of the
object’s motion as he did during the pre-instructional interview. His idea regarding the
object’s tendency to move is also displayed in the excerpt below.

Nejla: Suppose that I toss the same ball in the space where there is no near other
planets and no gravity what would happen?
David: In the hand, the ball accelerates because you are exerting a force on it in
whatever direction you are throwing it. And there isn’t any other force
acting against it. So it is going to accelerate to a certain speed. When it
leaves your hand it will stop accelerating. If there isn’t any friction or
gravity or anything to stop it, it would travel at a constant speed forever
until it hit something.
Nejla: Does it stop eventually?
David: No, there is nothing to slow it down.

After the instructional interventions, David provided a scientifically accepted
definition of force, and he also made ontological distinctions between the force concept
and other conceptual entities. As one part of the instructional interventions, David and his
group members were asked to draw a poster depicting their conception of force. As a
group they defined force as energy applied to an object to change its motion. When he
was reminded of his previous definition, he could distinguish the attributes of force and
energy at the ontological level.

Nejla: During the poster drawing activity, you and your group defined force as
the amount of energy applied to change an object's motion. Did you
change your idea about this definition?
David: I don't think it [force] is so much an energy anymore.
Nejla: How does your current definition differ from your earlier definition?
David: Energy has been couple years back in science. I can't remember what
definition they gave to energy. What I'm thinking of it… It might be even
related to energy. Energy, you know, it causes motion. It can give the
object kind of the power to move. You know, you have mechanical energy
electrical energy. It deals with electricity. I don't think force necessarily has to be energy. It could appear as energy. If, you know, ball is sliding across the ground and hits another ball it is going to exert a force on the second ball. And the second ball is gonna move. That is energy. I think that is what they were talking about. In this situation the energy is transferred from one ball to another. But the force is not transferred. The ball exerts a force on the other ball. So, that will cause it to move. Because it exerts a force greater than the friction. So the second ball moves. I don't think it necessarily has to be energy anymore. You know, gravity is not energy. It is not anything really tangible. It is a force. It is just the Earth is acting on whatever object is around.

David indicated that although force and energy were different entities they could be related in some ways. He was able to distinguish force and energy at the ontological level as he compared the transferability of these entities. For David, while energy was transferred from one object to another, force did not possess the same characteristic.

Before the instructional interventions, David held the idea that the direction of the force had to be the same with the direction of the motion. After the instructional intervention, he was able to recognize that the direction of the force might be different from the direction of motion.

David: I mean the force doesn't always have to be in the direction of the motion. It could be. Well I suppose in certain ways it could be because the motion and the acceleration is downwards that is where the force is. So but the motion of the ball is upwards for a little time and gravity is acting downward.

David not only stated that the direction of force and motion might be different, but he also identified two contexts in which the direction of the force and motion was the same and different. For him, the direction of the motion and force was different when a ball tossed up was moving upward, and the direction of the motion and force was the same when the ball was moving downward.
To sum up, David held the following ideas after the metaconceptual instructional interventions:

- Unbalanced forces cause objects to accelerate.
- Balanced forces cause objects to move at a constant speed.
- There is no need for net forces in the direction of an object’s motion. An object may move at a constant speed when the net force acting on it is zero.
- Exertion of a constant force does not always cause the object to move at a constant speed.
- Objects have the tendency to move at a constant speed. It is their natural state of being and needs no explanation.
- Inertia is an entity that has an amount. The amount of inertia depends on the speed of the object. It dissipates as the object slows down and becomes zero when it stops.
- Force is an entity that cannot be transferred from one object to another.
- The direction of force and motion may be different.

Changes in David’s Ideas about Force and One-Dimensional Forces

The data presented above indicate that throughout the instructional interventions a lot of David’s alternative ideas were altered. To sum up the change in his ideas, his ideas prior to the instructional interventions and after the instructional interventions are presented in Table 4.5. The changes in his ideas were not only at the factual level, but
**Pre-instructional Ideas**
- Force causes objects to accelerate.
- No differentiation of the outcome of balanced and unbalanced forces.
- Momentum or inertia object acquires keeps the object moving. Therefore, moving is not a natural state of objects.
- Inertia is an entity, which has an amount.
- As the object moves the amount of momentum or inertia reduces as a result of being overpowered by another force acting in the opposite direction.
- Direction of force dictates direction of motion.
- The amount of the force in the direction of the object’s motion must be greater than that of the opposing force.
- Continuous exertion of the same amount of net force causes object to move at a constant speed.

**Post-instructional Ideas**
- Unbalanced forces cause objects to accelerate.
- Balanced forces cause objects to move at a constant speed.
- Objects have tendency to move at a constant speed. Motion of objects does not require explanation.
- Inertia is an entity that has amount.
- The amount of inertia is related to the speed of the object. It dissipates as the object slows down.
- Force is not transferred from one object to another.
- Direction of force and motion may be different.
- There is no need for net forces in the direction of an object’s motion. An object may move at a constant speed when the net force acting on it is zero.
- Exertion of a constant force does not always cause the object at a constant speed.

<table>
<thead>
<tr>
<th>Pre-instructional Ideas</th>
<th>Post-instructional Ideas</th>
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<tr>
<td>Force causes objects to accelerate.</td>
<td>Unbalanced forces cause objects to accelerate.</td>
</tr>
<tr>
<td>No differentiation of the outcome of balanced and unbalanced forces.</td>
<td>Balanced forces cause objects to move at a constant speed.</td>
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<tr>
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<td>Direction of force and motion may be different.</td>
</tr>
<tr>
<td>Continuous exertion of the same amount of net force causes object to move at a constant speed.</td>
<td>There is no need for net forces in the direction of an object’s motion. An object may move at a constant speed when the net force acting on it is zero.</td>
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<tr>
<td>Exertion of a constant force does not always cause the object at a constant speed.</td>
<td>Exertion of a constant force does not always cause the object at a constant speed.</td>
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Table 4.5: David’s pre-instructional and post-instructional ideas about force and one-dimensional motion.

Also at the ontological level. For example, before the instructional interventions he explained the state of the object’s motion by comparing the amount of inertia or momentum with a force acting in the opposite direction. However, after the instructional interventions he displayed an ontological shift in his ideas by clearly stating that he did not consider inertia as a force anymore and by not comparing it with the force acting on
the object. On the other hand, David continued to believe that inertia has an amount. Although David did not consider inertia as a force anymore, he associated it with the speed of objects. It is clear that David assigned inertia from one scientifically unacceptable ontological category to another scientifically unaccepted ontological category after the instructional interventions. One major change in his ideas is his differentiation of the outcome of unbalanced and balanced forces. Before the instructional interventions, he thought that there had to be net forces in the direction of motion and exertion of constant net force produced constant speed. As he learned the effects of balanced and unbalanced forces on the objects, he accepted the idea that objects continued to move at a constant speed when the net force acting on them was zero and they accelerate even though the unbalanced forces acting on them were constant.

The changes in David’s ideas about force and motion were well reflected in his scores on pre- and post-FCI. Although he was able to respond correctly to 13 items of the FCI prior to the instructional interventions, he was able to answer correctly 26 items following the instructional interventions. Like the data from the pre- and post-instructional interviews presented above indicates, his scores on pre- and post-FCI point out his acquisition of a better scientific understanding and fewer alternative ideas about force and motion concepts after the instructional interventions.

*David’s Metaconceptual Processes about Force and One-dimensional Motion*

The purpose of this section is to describe David’s metaconceptual processes associated with his conceptions regarding force and one-dimensional motion. In an effort to facilitate students’ metaconceptual processes through various instructional activities,
David provided extensive evidence of his ability to engage in a variety of metaconceptual processes ranging from awareness of his ideas to more sophisticated higher-order thought. In order to make more sense to the reader, his metaconceptual processes are described by providing the context of the activities that he participated in. David’s metaconceptual processes are described within three main conceptual topics: definition of force, relationship between force and motion, and Newton’s First Law of Motion.

David’s Metaconceptual Processes about the Definition of Force. At the beginning of the instruction about force and motion concepts, the teacher requested that students draw a poster that depicted their understanding of force (see Activity 1, poster drawing activity in Appendix C). As David and his group drew their poster about their conception of force, he had the opportunity to recognize his ideas about force and what kind of entities he associated it with. As a group, they defined force as “energy applied to an object in a direction.” While presenting their poster to the whole class, David displayed evidence for his association of force with kinetic energy. The following excerpt is taken from David’s and his group’s poster presentation.

Teacher: Most of your things involve kinetic. What do you mean by kinetic? These are your key words [you provided to describe force]. So key words like kinetic mean what?
David: Forces kind of manifested as, you know, the traditional kinetic energy. You know, whenever an object has a kinetic energy it is moving.
Teacher: So forces are associated with motion or kind of motion? How have we differentiated between motions so far?
David: Positive or negative.
Teacher: Okay positive or negative.
David: Accelerating, decelerating.
Teacher: Accelerating, decelerating.
David: Three-dimensional one dimensional.
Teacher: Three-dimensional, one-dimensional… So did you say anything specific about any of those different types of motions?
David: Could be any of that.  
Teacher: So not specifically any type of motion but just motion?  
David: It could be like something like density or if here is just like... It is just like in star, it gets more dense. In the case of gravity if it is affecting something. Something that is not really moving. (Excerpt from poster presentation, activity 1)

At the time of the poster presentation, David expressed his own ideas about force (first-order metaconceptual awareness of his ideas). For example, he was able to make explicit reference to his association of force with kinetic energy (“Forces kind of manifested as, you know, the traditional kinetic energy. You know, whenever an object has a kinetic energy it is moving.”). David also displayed his idea regarding the outcome of force. For David, the outcome of force could be any kind of motion (“Teacher: Three-dimensional, one-dimensional… So did you say anything specific about any of those different types of motions? David: Could be any of that.”). Although David defined force as an entity that caused an object to accelerate prior to the instructional interventions, and he took a physics class before this study, it is clear that as he participated in the poster drawing activity, David did not consider acceleration as the outcome of force. Later in his conversation, he recognized a context in which force, specifically gravity, did not create motion (“In the case of gravity if it is affecting something. Something that is not really moving.”). In doing so, David displayed evidence for his ability to become aware of a context even at the very beginning of the instructional interventions (first-order awareness of contextual differences).

In order to encourage students to monitor the changes in their ideas throughout the instructional interventions, at the end of the instructional interventions students were given the posters drawn earlier about force (see Activity 12 in Appendix C). They were
During the presentation of the changes they made in their initial posters, it is obvious that David was able to monitor changes in their definition of force. As he engaged in this monitoring process, he became aware of his group’s earlier definition of force as “energy applied in a direction.” In doing so, David engaged in second-order awareness of initial ideas. He was not only able to reveal his group’s initial definition of force but he was also able to compare their earlier definition to their current definition of force (“What we added, first thing we did we changed the definition of force which we initially had as energy applied in a direction to an object. We now know that it has to be able to cause a change in the object's state of motion. Well it doesn't have to cause a change in the object’s state of motion but that is... be able to change its state of motion. It is the ability, the potential... it can change the object's state of motion.”). Although his group’s earlier definition of force did not involve acceleration as the outcome of force, at the time of this activity they were
successfully able to describe that force may cause objects to change their current state of motion.

As David revealed his group’s current definition of force, he displayed evidence of his ability to become aware of contextual differences regarding the outcome of force. He recognized that in some situations, force did not always cause a change in an object’s state of motion. (“Well it doesn't have to cause a change in the object’s state of motion but that is… be able to change its state of motion. It is the ability, the potential… it can change the object's state of motion.”). David was aware of his current idea that only unbalanced forces cause an object to change its state of motion (“David: …But now we have the effects of force being a change in the direction or speed which essentially is state of motion. Teacher: As long as the forces are? David: Unbalanced.’”) (first-order metaconceptual awareness of his ideas). At this point, the teacher reminded him of his group’s initial ideas regarding the association between force and motion. David revealed his idea that force did not always cause motion (“Teacher: One of the big ideas you had early on was motion and kinetic. Do forces necessarily involve motion? David: No, not necessarily.“) (first-order metaconceptual awareness of his ideas).

David was not only aware of his current ideas but he also demonstrated his ability to engage in second-order awareness of what he did not know before (“We added acceleration, balanced and unbalanced forces. Friction we added. Newton’s Laws are up here on the left. We didn't know about them before.”). He was aware that he did not know acceleration as the outcome of force, Newton’s Laws, and balanced and unbalanced force before. In his final journal entry, when David said that “My initial theories [about force] didn't provide a distinct way to account for acceleration,” he displayed evidence
for the same type of metaconceptual process (second-order metaconceptual awareness of what he did not know).

Collectively, throughout the instructional activities, in regard to the definition and outcome of force, David became aware of his current and past ideas about force, concepts that he did not know before and contextual differences regarding the outcome of force. During the first poster drawing activity, he realized that he associated force with kinetic energy and force caused any type of motion. He, however, became aware of a context in which force did not cause an object to move. During the second poster presentation, David not only became aware of his current ideas about force, but he also made reference to his previous understanding of force and what conceptual entities were missing in his initial conceptual structure. As he compared his previous ideas of force with his current ideas, he displayed evidence for his engagement monitoring the changes in his definition of force. He also became aware that he did not know the outcome of unbalanced forces, Newton’s Laws, and friction. David was also able to recognize the contextual differences regarding the outcome of force. He was aware that force did not cause a change in object’s current state of motion in every context.

*David’s Metaconceptual Processes about the Relationship between Force and Speed.* In this section, David’s metaconceptual processes regarding his ideas about amount of force and speed association are examined. One of David’s ideas he held prior to instructional interventions was about his association of the amount of force with the speed of the object. For David, exertion of a constant force caused objects to move at a constant speed. Throughout the instructional interventions, he was able to make explicit
reference to this idea at various points, especially when he participated in the tasks related to activity 2 (part A) (see Activity 2 in Appendix C).

In activity 2, students were asked to push a book on the table by exerting a constant force. Prior to discussing their ideas in groups, in order to facilitate students’ awareness of their ideas, students were requested to write a journal explaining the forces acting on the book as it moves on the table. David’s journal entry below clearly shows his awareness of his idea regarding the outcome of constant force.

David: The forces on the book are gravity and the table's reaction as before, but the force pushing the book is constant. This means the book accelerates rapidly in response to the force pushing it, and then moves at a constant speed to point B because a constant force is pushing it. It stops because of lack of force. The force applied increases the object's speed proportionally to the force. (Journal entry before group discussion, in response to activity 2)

David’s comments above indicate that he was capable of describing his idea that constant force produced constant motion (“…and then moves at a constant speed to point B because a constant force is pushing it.”). He also clearly provided information about his idea that the object’s speed increased as the amount of the force acting on it increased (“The force applied increases the object's speed proportionally to the force.”). At this point, David engaged in first-order awareness of his ideas regarding his association of force with the speed of the object.

After discussing their ideas in groups, students shared their ideas with all class members. As students stated their ideas, the teacher listed students’ ideas on a transparency. The excerpt below is taken from the class discussion about activity 2 (see Appendix C).
Teacher: Is there any relationship between the forces acting on the object on its way from point A to B? Is there any relationship between the forces acting on the object and its motion?
Lisa: Yes.
Teacher: What would they be? So what relationships are there between forces and motion?
Lisa: Forces create motion.
[Many students are talking at the same time].
Teacher: So the amount of force...and which force are you talking about? Like the hand? The amount of the force from the hand is directly proportional to the speed of the motion. Is that what you are saying?
Dennis: Yeah.
Lauren: I disagree with that.
Teacher: There's a disagreement, that's fine. Or...I always write or if there's a different idea [teacher is writing students’ ideas on a transparency].
David: [inaudible].
Teacher: So maybe you're pushing harder, harder and harder and it's still the same result. Is that what you're saying?
David: Right. Maybe when the force you're exerting is greater than the resistance of the object...
Teacher: So you have to overcome a certain....
David: Like if it were a graph of directly proportional...
Teacher: You're just talking about a different situation. Eventually what we want to do is apply our ideas to lots of different situations. Finish your idea.
David: Well maybe you have normal, just kind of liner graph of a directly proportional, the amount of force is directly proportional to the speed that the object moves at and then for a heavy object the graph stops at a greater force. I mean it's [motion is] zero at a greater force.
Teacher: So I'm not sure what you mean. Well hold on a second though, if I think what your saying... if this is velocity and this is force, you're saying for a really light object it might just take a really small force to get a decent velocity. I think that this is what I just heard you say, but if it's a really heavy object… [Teacher is drawing two graphs that depict the direct relationship between force and velocity for a light and for a heavy object].
David: Then the amount of force that it takes to get the velocity above zero.
Teacher: Is that what you're saying?
David: Yeah, Yeah.
Teacher: Do you understand what David is saying? For a heavy object you might need a lot bigger force before you can even get the velocity above zero.
David: Yeah that's exactly what I'm saying.
Teacher: Okay.
David: That's pretty good. (Except from class discussion after activity 2)
In the above exchange, David restated his idea that there was a direct relationship between force and the speed of the object. However, the metaconceptual ability he demonstrated is qualitatively different from simply stating his idea. He not only described a visual representation of his idea about the relationship between force and speed (a linear graph which shows the direct relationship between force and speed), but he also compared the relationship between force and speed for two different contexts (heavy objects vs. light objects). For him, in order to move a heavier object you had to exert a greater force compared to the force needed to move a lighter object (‘Well maybe you have normal, just kind of liner graph of a directly proportional, the amount of force is directly proportional to the speed that the object moves at and then for a heavy object the graph stops at a greater force. I mean it's [motion is] zero at a greater force’). His comments indicate that he was aware of the contextual differences regarding the amount of force required to move heavy and light objects (first-order metaconceptual awareness of contextual differences). Because David reflected on his existing ideas, this type of metaconceptual process is still at the first-order awareness level. Although the amount of friction (or opposite forces) makes a difference in the amount of force required to start an object’s motion, David made reference to the weight or mass of the objects in distinguishing the amount of force needed to start the object’s motion.

After students completed group and class discussions regarding activity 2, they were requested to write journals (see journal prompt 2 in Appendix C). They were asked to write about any differences they noticed between their own idea and other classmates’ ideas and whether those different ideas were attractive to them or not. Below is the excerpt taken from David’s journal entry written in response to journal prompt 2. His
journal entry included his comments about other conceptual elements, such as friction.

The excerpt below only describes segments related to his idea regarding force and speed association.

Constant force equals constant speed barring any changing conditions in the forces resistance. … One guy said the length of a push altered its speed, but I think a constant force will always equal a constant speed… We also talked about more force being necessary to get a heavier object to move.

One final idea is the speed of an object is directly proportional to the force applied to it. The higher the speed (which follows a direction concurrent with the direction of the force unless otherwise acted upon) the farther the object travels because it takes longer to slow down when the force subsides. (Journal entry written in response to journal prompt 2, after activity 2)

David’s journal entry above indicates that his metaconceptual ability went beyond first-order metaconceptual awareness of his own ideas. Throughout the group and class discussions, he was able to monitor other classmates’ ideas ("One guy said the length of a push altered its speed."). His metaconceptual ability to monitor other people’s ideas became more sophisticated as he compared his own idea with his classmate’s idea. He was able to monitor his friend’s idea that continued exertion of a force changed an object’s speed ("One guy said the length of a push altered its speed, but I think a constant force will always equal a constant speed."). He was able to monitor the consistency between his own idea and the idea of his classmate. At this point, David did not provide any reasons or justifications for his disagreement with his classmate’s idea. Although
he monitored the consistency of his alternative idea with a scientifically accepted idea, David displayed no signs of intention to evaluate these ideas. He believed that constant push always caused the object to move at a constant speed. David also depicted his mental representation about force and speed association for light and heavy objects. In doing this, he displayed evidence for his engagement in first-order metaconceptual awareness of contextual differences in the form of a graphical representation. David also revealed his idea that the direction of motion was the same with the direction of the force if no force was acting in the other directions (“…which follows a direction concurrent with the direction of the force unless otherwise acted upon.”) (first-order metaconceptual awareness of his ideas).

Throughout the instructional interventions, the teacher did not introduce the scientific explanations until students could not provide further explanation for situations discussed in instructional activities. After students’ ideas regarding the forces acting on objects in different situations were elicited though activities 1, 2, and 3, the teacher provided scientific explanations about the outcome of force. Although students were not asked to write a journal at that point, David was the only student in the class who wrote a journal to explain changes in his ideas. The following is the journal entry David wrote voluntarily.

Supplemental journal: I just realized during discussion the reason why an object accelerates when you flick it. Previously I was unable to explain the length or magnitude of the acceleration. I just knew it would accelerate, but I also thought it would stop acceleration while being pushed. But I now know [it would stop acceleration] without a decrease in force so that the finger exerts a force equal to whatever force resists it. I knew you had to have a greater force to get the object to move, and I thought acceleration would stop without the force stops. I know now it takes a greater force to acceleration and an equal force to attain constant speed.
In his supplemental journal entry, David’s comments provide evidence for his ability to engage in second-order type of metaconceptual awareness. In the excerpt above, he not only recognized his current ideas, but he was also able to refer to his initial ideas he held before (“I just knew it would accelerate, but I also thought it would stop acceleration while being pushed.”). He was aware of his former ideas that continuous exertion of a force caused the object move at a constant speed. David displayed his ability to monitor the changes in his ideas when he compared his initial idea with his current idea that objects moved at constant speed when the forces acting on them were equal. His comments indicate that he did not associate constant force with constant speed anymore.

To sum up, David made an explicit reference to his alternative idea that constant force caused an object to move at constant speed and an object’s speed increased as the amount of the applied force increased. He revealed his ideas not only through verbal comments but also through visual representations. David engaged in first-order metaconceptual awareness of contextual differences, as he compared the amount of force needed to move heavy and light objects. Although the amount of forces needed to move an object changes with the amount of opposite forces, David compared it in terms of the amount of matter. It is clear that he used a scientifically inappropriate contextual variable in making this comparison. David displayed evidence that he monitored the consistency with his alternative idea (constant force caused an object to move at a constant speed) with his friend’s idea that continued exertion of a force increased the speed of an object. Although David recognized the differences between his own idea and his friend’s idea he did not evaluate these ideas and did not show any sign of a change in his idea at that point. After the scientific knowledge about the outcome of forces introduced by the
teacher, David was able to make reference to his initial idea regarding his association of constant force and constant speed. He displayed evidence for monitoring changes in his ideas as he compared his initial idea with his current idea that balanced forces caused objects to move at a constant speed.

David’s Metaconceptual Processes about the Relative Amount of Forces Needed to Move an Object. In addition to his force and speed association, David held another alternative idea before the instructional interventions. He believed that the force in the direction of object’s motion had to be greater than the forces in the opposite direction even if the object was moving at a constant speed. David showed evidence of his recognition of this idea as he participated in various activities. The following extract is taken from a group discussion prompted by activity 2 (see Activity 2 in Appendix C). This discussion focused on the amount of forces acting on a book moving at a constant speed.

David: And the force of the finger pushing it across the table [at a constant speed]…
Brandon: Right, which I think is equal to the friction then.
David: No it doesn't. It just has to be enough to overcome the friction.
Brandon: Yeah right, that's what I put too.
Kevin: And it must be more than the friction.
Brandon: Exactly!
David: My hand is not overpowering Brandon's shoulder right now. [David pushed Brandon’s shoulder gently so that his shoulder did not move].
Brandon: My awesome power.
[Unrelated discussion].
David: Is there any relationship between the forces acting on the object on its way from point A to point B?
Brandon: Tell us what you think.
David: When the force of pushing is greater than the force of friction there is movement. I think that it's what we just talked about, right?
Brandon: Yeah. (Excerpt from group discussion, activity 2)
As David and his group members compared the force applied to push the book with friction, David clearly revealed his idea that the force exerted in the direction of the object’s motion had to be greater than friction. For him, objects could not move without a net force acting on them in the direction of their movement (“When the force of pushing is greater than the force of friction, there is movement.”) (first-order metaconceptual awareness of his ideas). In order to support his idea, David exerted on his friend’s shoulder a small amount of force that was not enough to move him. Although David was successful in engaging in first-order metaconceptual awareness of his experience, he misinterpreted the experiential evidence. In order to start an object’s motion, the applied force must be greater than the force in the opposite direction. On the other hand, the forces acting in the opposite direction must be equal to keep the object moving at a constant speed. Although the example he provided to defend his idea was related to the first situation (starting an object’s motion from being at rest), he used it to explain the second situation (keeping object to move at a constant speed).

After the teacher introduced the outcome of balanced and unbalanced forces, David displayed evidence that he monitored his initial idea regarding the need for a net force in the direction of object’s constant motion as he made that idea explicit (second-order awareness of her initial idea). In his supplemental journal entry, which he voluntarily made, he wrote:

… I knew you had to have a greater force to get the object to move, and I thought acceleration would stop without the force stops. I know now it takes a greater force to acceleration and an equal force to attain constant speed.
David not only became aware of his initial idea but also compared it with his current idea. He recognized his previous idea that the force acting in the direction of the object’s motion had to be greater to keep it moving (second-order awareness of his initial ideas). He contrasted his previous beliefs with the current ones as he revealed his current idea that “it takes a greater force to acceleration and an equal force to attain constant speed.” Although David did not directly say that he changed his ideas, through the contrast he provided it could be inferred that he monitored the changes in his ideas.

David displayed evidence for his engagement in similar types of metaconceptual processes (first-order and second-order awareness of ideas) regarding balanced and unbalanced forces in his journal entry written in response to journal prompt 4 (see journal prompt 4 in Appendix C). The following extract is taken from his journal entry. Only segments related to his ideas about balanced and unbalanced forces are presented here.

…The idea of the relations between forces and motion is still a little fuzzy, just in that it seems counterintuitive to have equal forces equal constant motion. I had originally thought that equal forces since they are balanced will cancel each other out and produce zero motion…. My ideas about balanced forces have changed. I used to think were static. This is something I have trouble believing but it's very quickly becoming natural to me as it sinks in. (Journal entry written in response to journal prompt 4, after activity 2)

David clearly demonstrated his difficulty in accepting the scientific idea that balanced forces caused objects to move at a constant speed. He recognized his initial idea that there could not be a motion if the forces acting on the object were balanced. His acknowledgement of the change in his ideas about balanced forces provides evidence for his ability to engage in metaconceptual monitoring of the changes in ideas.
In his journal entry written in response to the last journal prompt (see journal prompt 11 in Appendix C), David was not only aware of his initial ideas but he was aware that he did not know about unbalanced forces before (“I thought if an object was moving it was overcoming friction. I knew nothing about unbalanced forces.”).

In summary, in regard to his alternative idea about the need for a net force in the direction of an object’s constant motion, David explicitly revealed his alternative idea before the teacher introduced students to the scientific view about the outcome of balanced and unbalanced forces. After he acquired a scientific understanding regarding balanced and unbalanced forces, David compared his initial alternative idea with his current idea that balanced forces caused objects to move at a constant speed, indicating that he monitored changes in his ideas.

David’s Metaconceptual Processes about Newton’s First Law. Before the instructional interventions, David did not consider an object’s motion as a natural state. For him, there had to be something that kept objects moving. He believed that after objects were set in motion they acquired inertia or momentum that kept them moving. David considered inertia or momentum as a property possessed by objects which had amount and which dissipated as a result of being overpowered by another force in the opposite direction. Throughout the instructional activities, David engaged in various types of metaconceptual processes regarding his belief about an object’s natural state of being, momentum, and inertia. These processes were mostly seen in tasks related to activity 2 (part B), 3 and 7.
In the B part of activity 2 (see Activity 2 in Appendix C), students were requested to discuss the forces acting on a book after it was set in motion by a strong push by the hand. Students were notified that the hand did not keep pushing the book but it left the book after the book was set in motion. After a group discussion, the teacher asked students to summarize their ideas to the whole class. The following extract is taken from the class discussion about the ideas covered by the B part of activity 2.

Teacher: Question? What is or are the forces acting on the object from point B to C? Okay, so let's talk about that, from B to C. What are the forces? Are there any different forces? Are there forces that were there before but not now?
Lauren: The hand.
Teacher: The hand is not there anymore so...
Matt: So we're losing a force.
Teacher: So, all the same except the hand or not?
Brandon: The hand is there in the beginning.
Teacher: B is the instant I let it go.
[Many students are talking at the same time]
Connor: It is moving. So, its motion is a force.
Teacher: So what are you saying? [Are you saying] that there is a force there, but it's called the existing motion.
Brandon: That's what we will call it.
Connor: You can just call it our initial velocity.
Teacher: Is that a force though?
Lauren: Yes.
Teacher: The new force in this situation... Now tell me if you agree or disagree, this is just one person's statement... The new force is the existing motion of the book or car or whatever it is? [Teacher is writing students’ ideas on a transparency]. Any other ideas besides that? Anybody disagree with that? Or is this the opinion of the class, that now the force is the existing motion?
Students: Yes.
Teacher: What do you mean by a ‘new’ force? Um, what would you mean that a new force is now the existing motion? That something that has motion is itself a force?
David: I don't think it's necessarily a force, maybe the residue of another force. It is like the remaining of a force.
[Many students are talking and laughing].
David: You guys are making fun of me. I want to say something.
In the excerpt above, David articulated his idea that there was something that kept the object moving even after the hand was not pushing the object anymore (“It's like there was this force of the hand pressing the book and when the hand left the book it was still something causing the book to move maybe it's...”). He did not consider an object’s motion as a natural tendency, but rather he believed that it was caused by an entity acquired by the object after it was set in motion by a force. In his attempts to define the entity which kept the object moving, David used the words “residual,” “echo” and “remaining” of the applied force or momentum.

David’s awareness of his ideas went beyond recall of an existing concept. He was able to make an ontological distinction between the applied force of the hand and “the residual force.” At that point, David held the idea that continuous application of a force kept the object moving at a constant speed (see evidence on page 169). Based on this belief, David thought that the residual force which kept it moving had to be different from the applied force because the object was slowing down (“Probably because eventually the book is going to slow down so there probably is a difference between the
force and the residue force it has.”) His comments indicate that he had the ability to express first-order metaconceptual awareness of his ontological presuppositions. David also showed his awareness of his idea that “the residual force” dissipated as the object moves by agreeing with his classmate’s idea (Brandon: “Yeah that will eventually go away.” David: ‘Yeah.’)

David’s journal entry written in response to journal prompt 2 (see journal prompt 2 in Appendix C) showed his ability to monitor the content of the discussions in the class (monitoring information from other people). In journal prompt 2, students were asked whether they noticed any differences between their own ideas and other classmate’s ideas. His journal entry is below.

It was proposed that the applied force from the hand is gone when the hand leaves the book; but the motion of the book is caused by residual force. Good. I'm not the only one who thinks that. We debated whether the residual motion of the book was a force. It was suggested that it might be just energy transferred to the book [which keeps it moving]. The limitations on my ideas are probably most prevalent in situations I haven't thought of. If I didn't think of them, I couldn't account for them in my ideas. The main situations I thought of were just objects striking objects; my understanding is really limited. (Journal entry written in response to journal prompt 2, after activity 2)

Throughout the classroom and group discussions, he realized that other students in the class had similar ideas regarding the force acting on the object after it was set in motion. As his journal entry below demonstrates, David not only monitored what other students said about the force needed to keep objects moving, but he was also able to monitor the consistency between his own idea and other people’s ideas (“Good. I'm not the only one who thinks that.”) Although he displayed evidence for his monitoring of other students’ idea that the energy transferred from the hand kept the book moving, he did not indicate
any concurrence with this idea. David acknowledged that his ideas might have weaknesses in situations that he had not thought about. He realized that his current ideas were not adequate to explain the situation where one object strikes another object. At this point, although David was able to monitor an idea (energy transferred from the agent keeps the object moving) that was different from his idea, he did not show any sign of a change in his idea regarding residual force.

In activity 3, students were requested to discuss the forces acting on an object moving on a frictionless surface after it was set in motion by a strong push of the hand (see Activity 3 in Appendix C). Students were asked to choose between two alternatives regarding the force acting on the object (A. There is no horizontal force acting on the object; B. There is force acting on the object in the direction of its motion.). Students who chose different alternatives were requested to defend their ideas to each other. Below is an extract taken from David’s group debate. It is worth noting that at the time of this discussion students had not yet been introduced Newton’s First Law of Inertia and the definition of force.

Lisa: Are you A or B?
David: I'm A.
Connor: I'm A. No, wait, I'm B. I'm B. Can I go first? I said that there's horizontal force acting upon the object. I think that the hand, you still exert force over the object even though you're not still physically touching it. It's moving because of the initial force that you applied. That was my answer.
David: This is David and I am A. This just makes more sense. I think that the force acting is gone after your hand leaves the object. It's still moving. Friction slows it down. If there were friction the object would slow down. If there is no friction there is nothing to slow it down. It wouldn't have to counteract any kind of force. It's like a hockey puck it just moves in a direction. It doesn't counter anything.
Lisa: You're saying that after the push there is no force acting upon it?
David: There's this momentum, but if it was on a certain friction it wouldn't move. It would slow down because of friction. It almost keeps going because of the lack of friction.

Connor: I cannot follow what you said. What do you think about when something collides?

David: See that's the part that I'm not sure about. Because I mean it might depend on the mass of the objects that collide, or the weight, or what. If there is friction and if you just pushed it, it would eventually slow down and stop because friction acts upon it. Up to now we've just defined constant forces produces constant speed. But on a frictionless surface if you push it, it keeps going. There is nothing to slow it down.

Connor: But, you know, the initial force from your hand and like if friction is slowing it down the force from your hand is going to ...

Lisa: Yeah, the friction is overcoming the force from your hand more and more. But I did see the point of lack of force. That makes sense too. It's really not intelligent if you don't have enough information. I'm really interested in that conversation. It's hard. We can't really back it up.

David: Yeah, because we haven't done any kind of I mean ... Well, I've been trying to think of an example. But if a hockey puck, if it's just running across the rink, whether or not it has any hand pushing it across the rink, it keeps going. Yeah, if it runs into a marble, it's still gonna push the marble, but if it runs into the wall of the rink, it's not going to do anything. But it still has that momentum.

Lisa: Yeah, is momentum a force?

David: I don't know, but it's what we've been debating.

Lisa: Yeah, what's the definition of force?

David: Yeah, we don't even know what the definition of force is, so we can't really say whether the momentum is a force or not.

Connor: I think the momentum is where you ram your hand back and then shove it.

David: Yeah, I'm just trying to decide what exactly is momentum? But if it is moving is that a force or momentum?

Lisa: Yeah momentum is kind of like the aftershock force. But you don't know if it is force.

David: Right, exactly. I suppose this whole thing depends on the fact that none of us really know what force is. But I don't really know what it [momentum] is, but I think it is there.

Lisa: Yeah, it's just a guess. (Excerpt from group debate in response to activity 3)

In the excerpt above, when David defended one idea against another he demonstrated a very impressive metaconceptual ability to justify his ideas and he also indicated what he should have known to support his ideas. As the activity 3 required him to choose an
alternative that best described the situation under question, it is obvious that he made a judgment about the ideas presented in the alternatives. As he said “this [alternative A] just makes more sense,” he displayed evidence for comparing the relative plausibility of the two ideas. The debate among students showed that he did not make his decision just by guessing but rather he offered the reasoning behind his decision. His ability to make judgmental decision about competing ideas and providing reasons for why an idea was better than the other one clearly pointed out his engagement in metaconceptual evaluation.

Unlike the other students in his group, David believed that there was no force acting on the object as it moved on the frictionless surface. He based his reasoning on his idea that there were no other forces that slowed down the object. For him, the object kept going on frictionless surface without a force acting on it. As he defended his idea, he compared the forces acting on frictionless surface and on a surface with friction (“If there is friction and if you just pushed it, it would eventually slow down and stop because friction acts upon it. … But on a frictionless surface if you push it, it keeps going. There is nothing to slow it down”). In doing so, David became metaconceptually aware of contextual differences between the motion of objects on a frictionless surface and on a surface with friction. In order to support his claims, he also drew on his past experiences with hockey pucks (“Well, I've been trying to think of an example. But if a hockey puck, if it's just running across the rink, whether or not it has any hand pushing it across the rink, it keeps going”) (first-order metaconceptual awareness of experiences).

Although David defended that there was no force acting on the object, he repeatedly stated that the object had momentum (“There's this momentum, but if it was
on a certain friction it wouldn't move. … But it still has that momentum”). Having taken a physics course before, David was familiar with the concept of momentum. Unlike the scientific view, David considered momentum as the cause of object’s motion. The group discussion prompted by activity 3 gave him the opportunity to become aware of this idea. Later in their conversation, David realized that he did not know what he was referring to by momentum (“Lisa: Yeah, is momentum a force? David: I don't know, but it's what we've been debating”). As the conversation continued, David recognized that he even did not know what force is (“Yeah, we don't even know what the definition of force is, so we can't really say whether the momentum is a force or not”) (first-order metaconceptual awareness of what he does not know). Since he did not know the definition of force he was not sure whether momentum was considered as a force.

After activity 3, students were introduced to Newton’s First Law. In a journal prompt given after the introduction of Newton’s First Law, students were asked to write about whether they understood Newton’s First Law and in what ways it was different from their own ideas. In his journal entry written in response to journal prompt 4, David wrote “I understand Newton’s First Law. I know this because I comprehend that an object without something to make it move will remain stationary but if something makes it move (or stop) it will respond to that.” David was able to monitor his understanding of Newton’s First Law. He checked his understanding by stating the law in his own words. However, it is worth noting that his definition of Newton’s First Law involved an object’s tendency to remain stationary rather than to remain in motion. Although David was able to monitor his understanding of the Newton’s First Law by stating it in his own
words, this metaconceptual process did not guarantee that he had a scientifically accepted understanding of the law.

Having learned about Newton’s First Law and balanced and unbalanced forces, David displayed evidence for his engagement in several types of metaconceptual processes (e.g., metaconceptual evaluation, first-order awareness of ontological presuppositions, second-order awareness of initial ideas, and monitoring changes in ideas) regarding forces acting on objects as he participated in tasks related to activity 7 (see Activity 7 in Appendix C). In activity 7, students were provided with six pictorial representations that depicted the forces acting on a ball tossed up as it rising. Students were required to choose a representation that best illustrated their ideas. Students were asked to defend their idea to other students in their group. David initially chose the picture (alternative C) that showed a smaller force in the upward direction and greater force in the downward direction. Before the group discussion started, he changed his mind and defended the picture (alternative D) that showed only a downward force, namely gravity, acting on the ball. Below is an extract taken from the group debate initiated by activity 7.

Teacher: Build your case. You've got five minutes to talk about why you think your group is…
David: There's no force exerted up.
Kelsey: Force up. But then you're not pushing it anymore. So it gets smaller.
David: There's no force exerted up, but there would be a force exerted down. I think I changed my mind because he's not exerting it. There's no upward force exerted anymore other than momentum. I hope we learn that today.
Laura: So now we're just not sure.
David: We need another definition.
Laura: So we need to figure out something.
Kelsey: Because when you throw it up it goes up. To say that it's slowing down, so this force has to be smaller because it stops at the peak.
David: I don't think there is necessarily an upward force.
Kelsey: At the top so naturally that force should be almost gone.
Laura: So then it should be more like B or A? The forces have to be balanced so then wouldn't it be like this at the top? There's gravity and upward force.
David: If it were like B, then the ball would continue upward at a constant speed.
Laura: Or it would have stopped.
David: No.
Laura: Yeah.
David: It would have to decelerate before it would be able to stop. In your case, the forces would have to change in mid air and they're not going to do that because gravity is constant and there's no force being exerted on the ball upwards.
David: I think I change my mind then. I think it's D now.
Laura: It all depends on where exactly the ball is in the air. (Excerpt from group debate in response to Activity 7).

In the extract above, David demonstrated his engagement in metaconceptual evaluation as he defended his ideas against several ideas of his group members by providing justifications for his current idea. Although he had ideas similar to his friends’ ideas before the discussion started, he was able to stand for his ideas based on what he knew about the outcome of balanced and unbalanced forces. One idea held by one of the group member was the belief that the upward force acting on the ball dissipated as it slowed down and became equal to gravity at the peak of its trajectory. David defended the impossibility of this idea by referring to his knowledge that balanced forces could cause an object to move at a constant speed (“If it were like B, then the ball would continue upward at a constant speed.”). David also showed his disagreement by reflecting on his ontological presupposition that the amount of forces did not change in the air (“In your case, the forces would have to change in mid air and they're not going to do that because gravity is constant and there's no force being exerted on the ball upwards”). While the other students’ comments did not go beyond making their ideas explicit, David’s
comments above show that he provided justifications for his ideas based on his existing ideas and ontological presuppositions.

Although David maintained that there was no force acting on the ball in the upward direction, without knowing what it was he again brought up the word momentum (“There's no upward force exerted anymore other than momentum. I hope we learn that today”). At this point, I intruded into their group discussion with an attempt to give them an opportunity to further clarify their ideas.

Nejla: Do you think that there is a force acting on the ball in the upward direction?
David: Well that's why I think I revised my idea to think that it's D because after it leaves his hand there's really no upward force exerted on the ball. It is the momentum. It's moving, but it's constantly being decelerated. And initially that's what I thought, that it was the force of the ball moving upward but I don't necessarily know that it's a force.
Laura: It's just momentum.
David: It's just momentum. So we need to know whether momentum is considered a force.
Laura: If it is, then I think it's...
Nejla: Do you think that the upward thing is a force?
Kelsey: I think it is. Because if there wasn't a force going up, I think it would, I mean even with a car, I think it wouldn't move in that direction.
David: Inertia.
Laura: Yeah, it has the force. Force of motion.
Kelsey: If it stays in motion then that force has to overcome the other force.
Dan: It could be either of these [alternative A or C] though because it could go up really high and have this much, like you could throw it really hard and have gravity be like that [inaudible] to it. So it's either/or.
David: Yeah, but like how big do you say gravity would be compared to the other force.
Dan: Gravity is small and then you could throw it really hard.
David: But gravity is a constant force, so there would always be a constant difference [between gravity and upward force].
Kelsey: Another way to draw it is to have it be the same length as this and...
David: But the forces aren't gonna change in midair. Gravity is always constant.
Laura: No.
David: The arrow won't change because as it's [gravity is] pulling down, its inertia lessens because it's slowing it down. Like it has a lot here and eventually it slows down.
Kelsey: [inaudible]
David: Its movement will slow down. I don't know if its, see that's the thing, I don't know if momentum's the force or not. If momentum was the force, then you're right.
Laura: You have air resistance as a force and gravity are both up against the motion.
Dan: As it lessens its speed it has less force.
David: Right. But if air resistance and gravity are forces and they're going to slow the ball down, they have to be bigger than momentum or whatever force the ball may be exerting.
Kelsey: Right. So can you see…
David: It's not A though because it would be like launching a shuttle. (Excerpt from group debate in response to Activity 7)

At the beginning of this exchange, David displayed evidence for his engagement in monitoring the change in ideas (“Well that's why I think I revised my idea to think that it's D because after it leaves his hand there's really no upward force exerted on the ball.”).

In stating what his initial ideas were, David engaged in second-order awareness of his ideas (“And initially that's what I thought, that it was the force of the ball moving upward but I don't necessarily know that it's a force”). David initially thought that there was an upward entity, which was responsible for the ball’s upward motion. However, he was aware that he did not know whether the upward entity was considered a force (“So we need to know whether momentum is considered a force.’). It is worth noting that having been introduced to Newton’s First Law did not change David's idea that there must be something that kept the object moving.

In the remaining of part of the discussion, David continued to metaconceptually evaluate his ideas based on his knowledge about unbalanced forces and his ontological presupposition about force. For him, if there were an upward force acting on the ball, gravity would have to overpower it. He disagreed with Dan by showing the impossibility
of the alternative A (greater force in the upward direction and smaller force in the downward direction). For David, this alternative could not explain the situation because if it were right the ball would continue to move in the upward direction (“It's not A though because it would be like launching a shuttle.”). Throughout the discussion, David again made reference to his ontological presupposition that forces did not dissipate as the object moved in the air (“But the forces aren't gonna change in mid air. Gravity is always constant.”). As he defended his idea, David also recognized his idea that inertia was an entity that lessened as the object slowed down (“The arrow won't change because as it's [gravity is] pulling down, its inertia lessens because it's slowing it down”) (first-order metaconceptual awareness of his idea). In doing so, he revealed his idea that inertia had an amount and decreased as the object slows down.

After the group debate, students were asked to write a journal (see journal prompt 8 in Appendix C). Students were asked to explain whether they found any attractive ideas and whether they changed their ideas. Below is the extract taken from David’s journal entry.

…I didn't find any attractive ideas; though my idea changed during initial discussion. The only idea that struck me as truly odd was the idea that upward force would change as the ball's position changed. I think she must have been thinking of inertia as a force; otherwise it doesn't make sense. I initially thought that there was an upward force that I associated with the upward motion of the ball. After initial discussion I realized I had mistaken inertia for force. I hold that gravity is the only force. There is nothing acting upward on the ball, and the ball is negatively accelerating, so gravity must be the only force. Situations like a car putting on its brakes simulate force with opposite motion.

(Journal entry written in response to journal prompt 8, after activity 7)

David engaged in metaconceptual evaluation by stating that he “didn’t find any attractive ideas.” The idea that the upward force changes with the object’s position was not
plausible for him ("The only idea that struck me as truly odd was the idea that upward force would change as the ball's position changed."). He not only monitored another classmate’s ideas, but he was also able to recognize in what ways her theory was wrong ("I think she must have been thinking of inertia as a force; otherwise it doesn't make sense."). David also displayed evidence for his engagement in second-order metaconceptual awareness of his initial ideas. He maintained that he initially considered objects’ inertia as a force. ("I initially thought that there was an upward force that I associated with the upward motion of the ball. After initial discussion I realized I had mistaken inertia for force."). Being also aware of his current ideas, it can be inferred that he was able to monitor the changes in his ideas. At this point, David was not only able to compare his initial and current ideas at the factual level but he was also able to monitor ontological shifts in his ideas. Although David previously assigned inertia and force to the same ontological category, he was currently able to differentiate those two entities. According to his current ideas, the only force acting on the ball was gravity. Although David realized that he previously considered inertia as a force, his ontological distinction of these two entities was superficial, as he did not differentiate the ontological characteristics of force and inertia. It should be kept in mind that David considered inertia as a force which kept an object moving and dissipated as the object slowed down prior to the instructional interventions. In explaining the motion of objects, he compared the amount of inertia with other forces. After the instructional interventions, although David did not compare inertia with other forces and directly stated that he did not consider inertia as a force, he thought that inertia had an amount and decreased with objects’ speed. Throughout the instructional interventions David did not show any signs of
monitoring the scientifically accepted ontological characteristics of inertia (inertia as a property of objects) and distinguishing it from the ontological characteristics of force (force as an action).

Students were given a table in which they were provided with several situations near the end of the instructional interventions (see journal prompt 11 in Appendix C). For each situation in the table, they were asked to write their initial ideas and current ideas. After filling out the table, they were requested to write a journal in which they examined the consistency of their initial and current ideas across different situations (see journal prompt 11 in Appendix C). Below is an extract from David’s journal entry written in response to that prompt.

… I also believed in residual forces, which is now inertia. Therefore, my ideas came from friction having to overcome this residual motion. When in the air, I pictured this force [residual force] being reduced by gravity and when on a surface with friction I pictured it being reduced by friction. So my ideas took gravity or friction having to spend part of its force overcoming this residual force. (Journal entry written in response to journal prompt 11)

In the extract above, David commented on his initial idea regarding residual forces, and he was also able to monitor which conceptual entity he replaced his initial idea of residual force (“I also believed in residual forces, which is now inertia.”). At that point, he believed that inertia kept objects moving rather than residual forces after they were set in motion. In the remaining part of his journal entry, David showed that his ability to become aware of the contextual differences went beyond the first-order metaconceptual awareness. He was clearly able to make reference to his initial ideas he held for different contexts. He was able to compare his idea regarding the dissipation of residual force in two different situations. In a situation where there was friction as an opposing force, he
initially thought that residual force was reduced by friction. When there was gravity on
the other hand, he previously believed that residual force was reduced by gravity (“I
pictured this force [residual force] being reduced by gravity and when on a surface with
friction I pictured it being reduced by friction.”). In his engagement in second-order
awareness of contextual differences, David compared his initial idea of residual force
between two similar contexts that shared the same contextual variable. In both situations
(motion on a surface with friction vs. motion in the air in the upward direction), there is a
force in the opposite direction of motion. Thus, it was unlikely for David to notice any
inconsistencies in his use of initial ideas.

To sum up, in regard to his ideas about the natural state of objects, David
recognized his ideas that residual force or momentum kept objects moving. He made an
ontological distinction between applied force and his idea of residual force as he stated
that objects slowed down when residual force was acting on them, and they move at a
constant speed when applied force was acting on them. Although David monitored his
classmate’s idea that energy transferred kept an object moving, David neither compared it
with his own idea nor reflected on the plausibility of that idea. As he defended his ideas,
he became aware of the differences in the motion of objects on frictionless and on a
surface with friction. He used this information to justify his idea that there was no need
for a force to keep an object moving on a frictionless surface. To support his claims, he
drew on his experiences with hockey pucks. Although he defended the idea that there was
no need for a force to keep an object moving, he repeatedly revealed his idea that
momentum kept the object moving. As he discussed his ideas with other classmates, he
realized that he did not know what force and momentum were. After the teacher
introduced Newton’s First Law, David defended the idea that there was no need for a force in the direction of an object’s motion by providing justifications based on what he knew about the outcome of balanced and unbalanced forces and his ontological preposition about force. He also monitored the changes in his ideas as he realized that he initially considered inertia as a force. Although he distinguished force and inertia, he did not explicitly differentiate the ontological characteristics of these two entities. David was also able to realize his use his initial idea regarding residual in two contexts. Since the contexts shared the same variable (i.e., force in the opposite direction of motion), his awareness of his use of ideas in different context did not allow him to recognize any inconsistencies in his ideas.

Summary of David’s Metaconceptual Processes about Force and One-Dimensional Motion

As indicated in the data presented above, David did not have difficulty in explicitly referring to his ideas about force and one-dimensional motion. Metaconceptual instructional activities used in this study provided David with the opportunity to become aware of his ideas in the form of making his ideas explicit through communication tools including verbal and written comments and drawings. The excerpts taken from his group or class discussions and journal entries clearly demonstrated evidence for his awareness of his ideas that (a) exertion of constant force caused objects to move at a constant speed; (b) there was a directly proportional relationship between force and speed; (c) the force in the direction of the object’s motion had to be greater than the opposing force; (d) the outcome of the force could be any kind of motion; (e) after an object was set in motion by
an applied force, a residual force or momentum kept the object moving; (f) the amount of residual force decreased as objects slowed down; (g) the amount of inertia decreased as objects slowed down; and (h) if there was no other force acting on the object, the direction of the force and motion would be the same. As the content of the ideas listed above indicates, David became aware of most of his alternative ideas that he held prior to the instructional interventions, along with other ideas that he constructed throughout the instructional interventions.

David was not only aware of his idea about forces and motion, but he also made reference to the elements of his conceptual ecology, such as experiences, ontological presuppositions and contextual variables. David became aware of his ideas and elements of his conceptual ecology for two purposes: to provide an explanation about a phenomenon in an attempt to deal with the demands of the instructional activities and to provide justifications for ideas in an attempt to evaluate competing ideas. For example, as David attempted to justify the idea that there was no need for a force to keep an object moving on a frictionless surface, he compared the motion of an object on a frictionless surface or on a surface with friction. As David attempted to describe his idea regarding force and speed associations, he compared forces needed to start an object’s motion for heavy or light objects. When David engaged in first-order metaconceptual awareness of contextual differences, he not only made explicit reference to environmental characteristics and characteristics of the objects, but he also recognized the applicability of an idea or principle to different contexts. Specifically, he was able to recognize that forces acting on objects did not cause acceleration in all situations. David displayed evidence of using more sophisticated metaconceptual awareness of contextual differences.
as he compared his initial ideas across different contexts, namely, as he engaged in second-order metaconceptual awareness of contextual differences. He was able to compare his use of his initial idea about residual force in two contexts where gravity and friction were the opposing forces. The contexts that he referenced shared the same contextual variable, an opposite force in the direction of an object’s motion.

While he explicitly stated the theories he held at the time and defended his present ideas against other ideas, David also made reference to his past experiences. For example, to support his ideas regarding an object’s motion on frictionless surfaces, he drew on his experiences with hockey pucks. At some points as David became aware of his experiences, he displayed evidence that he did not interpret his experiences in the way the scientists did or he did not use appropriate examples to justify his claims. For example, to support his ideas regarding the amount of force needed to keep the object moving at a constant speed, he made reference to his experience in which an object was accelerating rather than moving at a constant speed.

As David made his ideas explicit or evaluated competing ideas, he became aware of his ontological presuppositions regarding the force concept. For example, while he defended his ideas, he revealed his ontological presupposition that the amount of forces did not change in the air. When he made reference to his idea regarding residual force, he made an ontological differentiation between residual force and applied force. For him, since the object slowed down after it was set in motion by an applied force, the residual force acting on the object as it moved had to be different from the applied force. David displayed evidence that could make a distinction between inertia and force. However, he did not make an explicit reference to the ontological characteristics of these two entities.
David displayed evidence that he was not only aware of his current ideas, but he had the ability to become aware of his past ideas. At many points after learning about the outcome of balanced and unbalanced forces, he was successfully able to make reference to his initial ideas that constant force caused objects to move at constant speed and there was a need for net forces in the direction of object’s motion. After learning about Newton’s First Law, David displayed evidence of his awareness of his initial idea about residual force. His ability to engage in second-order awareness of his initial ideas clearly shows that he was able to monitor his own ideas at the time he made explicit reference to those ideas.

As David participated in group and class discussions, he recognized what he did not know. For example, he realized that he did not know what he was referring to by momentum or force. Similarly, after learning about balanced and unbalanced forces, he engaged in second-order metaconceptual awareness of what he did not know when he became aware that he initially did not know about them.

David was also able to monitor changes in his ideas. As he monitored changes in his ideas, he first became aware of his initial ideas and compared those to his current ideas. He was successfully able to compare his initial definition of force with his current understanding of force. He was also able to compare his current ideas regarding the outcome of balanced and unbalanced force with his initial ideas about the amount of force needed to keep objects moving. David was not only able to monitor changes in factual information, but he was also able to monitor the ontological shifts in his ideas. For example, he was able to state that he did not consider inertia as a force anymore. In doing so, he showed that he assigned inertia to a different ontological category.
Another qualitatively different metaconceptual process David engaged in was monitoring understating of ideas. Although David monitored his understanding of Newton’s First Law by restating it in his own words, his statement of the Newton’s First Law showed that he did not have a scientifically accepted understanding of it. His understanding of the Newton’s First Law did not involved an object’s tendency to remain in motion, but it only involved object’s tendency to remain stationary.

Throughout the group and class discussions, David was not only able to recognize his personal stock of information, but he was also able to monitor other people’s ideas. His engagement in this type of metaconceptual process was seen in his journal entries when he clearly explained what his classmate’s thought as they discussed their ideas. David did not only state other people’s ideas, but he was also able to compare the consistency between his own ideas and other people’s idea.

David demonstrated evidence for his engagement in metaconceptual evaluation as he made judgmental comments about why an idea works better than another idea. He compared the relative plausibility of ideas by using expressions such as makes more sense, attractive, or truly odd. In addition to using explicit expressions to refer the plausibility of ideas, David also engaged in metaconceptual evaluation as he chose an idea from several alternatives and provided his reasoning for his judgmental decisions. As David defended his ideas, he drew on his existing knowledge, ontological presuppositions, or experiences. For example, he commented on the implausibility of one of his friend’s idea (the forces are balanced at the peak of the ball’s trajectory) by making reference to his knowledge about balanced and unbalanced forces. Similarly, he revealed his ontological presupposition about force that the amount of forces did not dissipate in
the air as he showed his disagreement with an idea. In order to support his claims that there was no need for a force to keep an object moving on a frictionless surface he drew on his past experience with hockey pucks. As David evaluated ideas, he recognized the limitations of his current conceptual structure. For example, he realized that he should have known the definition of force to ensure the validity of his claims. He also became aware that he did not know whether momentum was considered within the same ontological category of the force.

Lisa’s Case

Lisa is an eleventh grade student in the experimental group. Unlike David, she did not take any physics courses before this class. Lisa took this course because she was planning to take an advanced placement physics course the following year, and she wanted “to learn enough to have a good background” for that course. She did not like memorizing subjects, but she claimed that she learned “best by knowing the ‘why’ behind a fact.” Lisa wants to study chemical or biomedical engineering at college. She was chosen as one of the case students because of her low score on the FCI administered prior to instruction. Out of the 30 items, she was able to correctly respond to 8 items on the pre-instructional FCI, indicating several alternative ideas about force and motion. She correctly answered 27 and 24 items on the FCI administered immediately following and nine weeks after the instructional interventions, respectively.

Lisa’s Pre-Instructional Ideas about Force and One-Dimensional Motion

Before the instructional interventions started in the experimental group, Lisa defined force as “an action that would act upon an object.” Although she used examples
in which objects are accelerating as a result of being exerted by a force, Lisa could not differentiate acceleration as the outcome of force from any kinds of motion.

Nejla: How do you know that force is acting on an object?
Lisa: Previous experience.
Nejla: What kind of previous experience? What experiences tell you that force is acting on an object?
Lisa: Eventually something will stop and that’s because of friction. A ball will drop because of gravity. You push something it will move.
Nejla: All of your examples involve motion. Do you associate force with any kind of motion?
Lisa: Any motion.
Nejla: What about constant motion?
Lisa: Yes.

The excerpt taken from the interview conducted prior to the instructional interventions shows that, for Lisa, force could create any kind of motion. Although she agreed that force might cause objects to move at constant speed, she did not specify that only balanced forces or no forces produced constant speed. Throughout the interview, like David, Lisa displayed no signs of knowledge about the outcome of balanced and unbalanced forces. She had an interesting belief that an object could not move at a constant speed if there was a force acting on the object in the opposite direction of its motion.

Nejla: Is there a way to keep it moving at a constant speed?
Lisa: No. Because you have two forces acting on it.
Nejla: If there are two forces acting on an object do you think that the speed will not be constant?
Lisa: No, the speed won't be constant because the force of your push increases the speed. Then as friction acts more on it, it slows.

For Lisa, the only way to keep an object moving at a constant speed is removing the force acting in the opposite direction of the object’s motion.

Nejla: Okay. What should I do to keep the book moving at a constant speed?
Lisa:  Take away friction?
Nejla:  Take away friction. I want to move this book at a constant speed from point A to point B what should I do? Other than taking away friction?
Lisa:  If you push it harder it's still not going to be constant, the speed is not going to be constant.

The excerpt above points to Lisa’s idea that the object could not move at a constant speed on a surface with friction unless the friction was removed from the surface. In situations where there were no opposing forces, she held the idea that the objects moved at a constant speed even though a force acquired from the agent to the objects was acting on them. For example, for her, a ball tossed up in space, where there was no gravity, continued to move at a constant speed even though she thought that the force from the hand was still acting on it.

Nejla:  What about the force I used to throw the object up? Is it still acting?
Lisa:  Yes.
Nejla:  Does it increase, decrease, or stay constant as it moves?
Lisa:  Constant.
Nejla:  Why do you think it’s constant?
Lisa:  Because there’s no other force acting upon it.
Nejla:  What about its speed?
Lisa:  Speed is the same [constant].

Although Lisa’s idea that the object would move at a constant speed after it was set in motion in the absence of opposite forces is scientifically acceptable, her idea that the object would move at a constant speed while there was a constant force acting on it is in contrast with the Newtonian view of motion.

Another alternative idea that Lisa possessed was her belief that there was a need for net forces in the direction of an object’s motion even if the object moved at a constant speed. Similar to David, Lisa believed that the force in the direction of the object’s
constant motion had to be greater than the force in the opposite direction. She displayed evidence for this belief when she was asked to compare the amount of forces acting on a car and truck moving together at a constant speed.

Nejla: Okay. After a while the car has pushed the truck and they have reached a constant, cruising speed they move at that constant speed together. Do you have any idea about the amount of the forces acting on the truck or the car?
Lisa: The friction is still active on them. The car's force overcomes that.
Nejla: What do you mean by overcomes?
Lisa: The force of the car must be more than the force of friction.

For Lisa, the force exerted by the car had to be greater than friction in order to keep moving at a constant speed. Her statement regarding the need for a greater force in the direction of constant motion is in contrast with the scientific view that balanced forces cause constant motion.

Throughout the interview in various situations, Lisa displayed extensive evidence for her alternative idea that objects acquired a force when they were set in motion by an agent. In contrast to the Newtonian view, Lisa believed that the act of setting object in motion impressed in the object a force that kept the object in motion even after having lost in contact with the agent. Similar to David, Lisa believed that there was a need for an entity that kept objects moving. While that entity was momentum, inertia, or a force for David, it was an acquired force for Lisa. She considered force as an acquired property of objects that moved as result of an agent pushing or pulling them. She made explicit reference to this idea when she was asked the forces acting on a book moving across a table after being pushed by my finger.

Nejla: Okay. Next question. I push this book across the table from this point to this point. Let’s call this point A and this point B, okay? What are the forces acting on the book as it moves from point A to point B? You may
Lisa: Okay. Well you pushed the book. So you’re a force and friction slows the book and that’s a force and the table prevents it from dropping so that’s a force and gravity is always pulling down on it.

Nejla: Could you draw a figure showing the forces?

Lisa: Yes, because the book is moving.

Nejla: Does it [force from hand] increase, decrease, or stay constant while it moves?

Lisa: Constant.

In the excerpt above Lisa displayed her belief that the force applied on the book to set it in motion was still being exerted on it even after it lost contact with my finger. For her, the acquired force was responsible for the book’s horizontal motion. Unlike students’ alternative ideas regarding the dissipation of acquired force that was reported extensively in the literature, Lisa thought that the amount of the acquired force did not change but rather stayed constant as the object moved. In the case of vertical motion, where gravity was the opposing force, Lisa restated the same belief.

Nejla: Could you describe what happens when I throw this ball up in terms of its speed and the forces acting on it? [A small ball is tossed up by the researcher].

Lisa: You exert a force upward when you toss it. Gravity exerts a force downward and eventually stops the ball.

Nejla: Okay, while it moves upwards, the force I used to throw this ball up, does it still exert on the ball or is it just gravity?

Lisa: The force that you threw it up at will affect the ball until it reaches a point where it stops moving and gravity takes over.

Nejla: Does it decrease, increase, or stay constant as it moves up?

Lisa: The force stays constant.

Nejla: Okay and what happens at the peak?

Lisa: There is no... there is no force [from hand]. Gravity is acting on it.

Nejla: What are the forces acting on the ball as it falls?

Lisa: Gravity.

Nejla: Is there another force?

Lisa: Well air forces but mostly gravity.
Nejla: Does is speed up, slow down or stay constant has it falls?
Lisa: The force stays constant and velocity speeds up.
Nejla: How strong are the forces compared to each other as they travel up?’
Lisa: Gravity is stronger than the force used to throw it up.
Nejla: Why do you think that gravity is stronger?
Lisa: Because gravity wins in the end. The ball does not continue upward. The ball will eventually fall.

Lisa’s statements above indicate her belief about acquired force in the direction of the ball’s upward motion. She maintained that the acquired force stopped acting on the object when it reached the peak of its travel. It is obvious that she explained the upward motion of the ball with the acquired force acting on the upward direction. Similar to her ideas in the case of horizontal motion, she believed that the acquired force from the agent did not dissipate as the object slowed down, but stayed constant throughout its travel in the upward direction. For Lisa, as the ball slowed down, gravity had to be greater than the acquired force.

For Lisa, there was not only a need for a force to keep the object moving in situations where there were opposing forces but force was also needed to maintain the object’s motion in the absence of opposing forces. For example, as shown in the excerpt below, she stated that a book set in motion on a frictionless surface acquired a force that kept it moving at a constant speed. She thought that the acquired force stayed constant throughout the book’s motion. It is clear that Lisa did not consider the object’s motion as a natural state of objects but rather, for her, there was a need for a force that kept the object moving even in the absence of opposing forces.

Nejla: Okay. Suppose that I push this object, this book on a very smooth surface where there is no friction. What would happen if I pushed the object?
Lisa: It would remain at a constant speed.
Nejla: Will it slow down or increase its speed eventually?
Lisa: No, not unless it come in contact with another force.
Nejla: What forces will be acting on a frictionless surface?
Lisa: You still have gravity and you still have air force which I guess could affect its movement, make it not constant.
Nejla: Is there a force acting on the book other than gravity and an air force?
Lisa: Well it is moving. So it has a force of your push still.
Nejla: Is it still exerting on the book while it’s on a frictionless surface?
Lisa: Yes, it’s exerting force.
Nejla: Does it increase, decrease, or stay constant while it moves?
Lisa: Stays constant.
Nejla: Why do you think it stays constant?
Lisa: Because there is no force acting against your push.

In summary, prior to the instructional interventions Lisa possessed the following ideas:

- Force creates any kinds of motion.
- She could not differentiate the outcome of balanced and unbalanced forces.
- After objects are set in motion, they acquire a force that keeps them moving. Therefore, moving is not considered as a natural state of objects.
- Force acquired by an object acts in the direction of the object’s movement and stays constant throughout the object’s travel.
- Objects cannot move at constant speed if two forces in opposite directions act on the object.
- The amount of force in the direction of the object’s constant motion must be greater than the amount of the force acting in the opposite direction of the object’s motion.

**Lisa’s Post-Instructional Ideas about Force and One-Dimensional Motion**

Prior to the metaconceptual instructional interventions, Lisa believed that force created any kind of motion. After the instructional interventions, Lisa defined force as “push or pull or an action that causes acceleration.” Her definition of force did not
involve any type of motion, but she could clearly state that force caused objects to accelerate. Her statements below show how her ideas changed after the instructional interventions.

Nejla: How do you know that forces are acting on an object?
Lisa: You can see it. Like you can if I push a book it'll move. And something has caused that.
Nejla: Ok. Do you think that anything that is moving is being exerted by a force?
Lisa: No, because you can have constant velocity and there will be no force acting on it or balanced forces.

As the above excerpt indicates, Lisa did not associate force with motion anymore. For Lisa, objects could move at a constant speed even when there were no forces acting on them.

Previously, Lisa was also unable to differentiate the outcome of balanced and unbalanced forces. She held the idea that objects could not move at a constant speed if two forces in the opposite directions were acting on them. After the instructional interventions, she displayed evidence that she acquired a scientific view about the outcome of balanced forces. When she was asked how an object could move at a constant speed, she showed her scientifically accepted idea that objects could move at a constant speed when the forces acting in opposite direction were equal.

Nejla: What should I do to keep the book moving at a constant speed?
Lisa: You have to take away friction.
Nejla: Take away friction? Ok. What else can I do if I cannot take away friction?
Lisa: Then you apply a force equal to the friction.

In response to further questioning, Lisa showed that she not only knew the outcome of balanced force but she also acquired the scientific view that unbalanced forces caused objects to accelerate.

Nejla: What would happen if one of the forces is greater that the other one?
Lisa: Then the book would move.
Nejla: Move at a constant speed or?
Lisa: It would accelerate.

One idea Lisa possessed before the instructional interventions was her view that objects set in motion acquired a force that kept the object moving. Previously, for Lisa, acquired force acted in the direction of an object’s motion even in situations where there were no opposite forces. After the instructional interventions, in various situations Lisa displayed evidence for the change in her ideas about the acquired force. For example, when she was asked the forces acting on a book sliding on the table, Lisa did not state any force in the direction of the book’s motion.

Nejla: Next question. Suppose that I push this book on the table just like this and it moves from point A to B. Ok. What are the forces acting on this book at point A, while it travels from point A to B, and at point B? [Researcher pushed a book and let it slide on the table]
Lisa: At point A it accelerates and your force is exerting on the book. And from point A to B the only force acting on the book is friction.
Nejla: Friction.
Lisa: Yeah. At point B. There is no forces acting on the book. Well gravity and normal force. They are acting at all points.
Nejla: What would you say about the speed of the book as it moves from point A to B?
Lisa: The speed is decreasing.
Nejla: Why is it decreasing?
Lisa: Because the friction is accelerating, in this case it is decelerating it.
Nejla: You said that from point A to B the only force acting on the book is friction and additionally gravity and normal force, right?
Lisa: Yeah.
Nejla: At which direction does friction act?
Lisa: It acts in the opposite direction of motion.

Unlike her response in the pre-instructional interview, Lisa stated that there was no need for a force in the direction of the book’s motion. Other than gravity and the normal force, she thought that the only force acting on the book in the opposite direction of its motion
was friction. The change in her idea about acquired force was not confined to horizontal motion. Similar to her ideas in the horizontal motion, she did not state any acquired force was acting on the ball that was thrown up.

Nejla: Could you explain what happens when I throw this ball up as it travels down? What happens at the peak and as it moves up?
Lisa: After you throw it the only force acting on it is gravity and gravity is constantly going down [in the downward direction]. Then at the peak gravity is still acting on it. It just has no velocity. And it is traveling down and still has gravity.
Nejla: What would you say about the speed of the ball?
Lisa: The speed as it is going upward is decreasing. As it is going downward it is increasing.
Nejla: What about at the peak?
Lisa: At the peak there is no speed.
Nejla: Is it accelerating at the peak? Lisa: It is accelerating downward.

In contrast to her response in the pre-instructional interview, Lisa maintained that the only force acting on the ball throughout its movement was gravity. When she was reminded of her previous idea of acquired force in the direction of ball’s upward motion, Lisa stated that she changed her idea of acquired force with inertia.

Nejla: During our first interview you said that as the ball travels up force that you exerted on the ball to throw it up and gravity are acting on the object. Do you still hold this idea?
Lisa: No, I replaced it with the inertia. The ball is continues its path upward but it is decelerating as a result of gravity. The idea of inertia kind of overcame the idea of force of my push.

Although Lisa said that she replaced her idea of acquired force with inertia, like David’s pre-instructional idea of inertia, there was a probability that she assigned some characteristics of force (amount and direction) to the inertia concept. With the aim of further clarification of her idea of inertia, Lisa was asked whether inertia was an entity that was comparable to gravity.
Nejla: And [in previous interview] you also said that gravity is greater than the force of your push. If you replace the force of your push idea with inertia could you say that gravity overcomes inertia or, in other words, gravity is greater than inertia?
Lisa: Well the inertia does not really have any force at all. So they cannot be compared. I mean since it is no force and gravity obviously has acceleration. So it [inertia] is just the fact that the ball is moving in that direction.

As her statements above indicate, Lisa assigned force and inertia into different ontological categories. She not only stated directly that inertia was not a force, but she also maintained that inertia was an entity that was not comparable to a force. It is obvious that Lisa did not consider inertia as an action or process but, rather, for her, inertia was a scientific “fact” that objects continued to move in a direction after they were set in motion. Unlike David’s idea that inertia had an amount and decreased as the object slowed down, Lisa considered inertia as a “fact.” In doing to, Lisa assigned scientifically acceptable attributes to force and inertia.

Previously, Lisa thought that even in the absence of opposing forces there was a need for a force acing on the object to keep it moving at a constant speed. She explained the motion of the object with a force acquired after it was set in motion. Her responses below show how her ideas changed after the instructional interventions.

Nejla: Ok. Suppose that I push this book on a very smooth surface, a frictionless surface. What would happen if I push this book?
Lisa: It will continue. After you the force is applied it will continue at a constant speed.
Nejla: Does it stop eventually or does it float around?
Lisa: No it just keeps going until it is acted upon by another force.
Nejla: Why do you think it'll move forever?
Lisa: Because there is nothing stopping it. There is nothing on its way. So it keeps moving.
The excerpt above shows that, for Lisa, there was no longer a need for an acquired force to keep the object moving at a constant speed. Lisa maintained that there was no force acting on the book on a frictionless surface after it was set in motion. She stated that the book would continue to move until another force acted upon it. It is obvious that, for Lisa, the motion of the ball no longer required an explanation. She considered motion as a natural state of objects.

To sum up, Lisa held the following ideas after the instructional interventions:

- Force is a push or a pull that causes objects to accelerate.
- An object moves at a constant speed when the forces acting on it are balanced, and it accelerates when the forces acting on it are unbalanced.
- There is no need for a force that keeps objects moving. Objects can move at a constant speed without force acting on them.
- Natural state of objects can be motion. There is no need for an explanation for an object’s motion. Objects keep moving until a force is acting on them.
- Inertia is not a force. It does not have amount and cannot be compared with the amount of a force. It is the fact that objects continue to move in a direction.

Changes in Lisa’s Ideas about Force and One-Dimensional Motion

Throughout the instructional interventions, Lisa changed many of her alternative ideas that she held prior to the instructional interventions. To sum up the changes in Lisa’s ideas, her ideas prior to the instructional interventions and after the instructional
interventions are presented in Table 4.6. A drastic change is seen in her idea about the force that objects acquire after they are set in motion. Previously, for Lisa, the acquired force in the direction of object’s motion kept it moving. After the instructional interventions, Lisa successfully acquired the scientific view of inertia. For her, there was no longer a need for a force acting in the direction of object’s motion; instead, objects had the tendency to move until a force acted upon them. As Lisa thought that inertia did not have amount and could not be compared with the amount of a force, she displayed evidence that she assigned the inertia concept to a scientifically accepted ontological category. Unlike David, who considered inertia as an entity which had an amount and associated inertia with the speed of the object, Lisa considered inertia as a “fact” that objects continued to move in a direction. Lisa’s association of force with any kind of motion was another idea that she held prior to the instructional interventions. After the instructional interventions, she did not only state that force caused objects to accelerate, but she was also able to differentiate the outcome of balanced and unbalanced forces. She previously thought that objects could not move at a constant speed when two forces in opposite directions acted upon them. After the instruction, Lisa was able to successfully grasp the scientific understanding that balanced forces caused objects to move at constant speed, and unbalanced forces caused objects to accelerate. As Lisa learned the outcome of balanced and unbalanced forces, she accepted the scientific view that there was no need for net forces in the direction of an object’s constant motion.
Pre-instructional Ideas | Post-instructional Ideas
--- | ---
- Force creates any kinds of motion. | - Force is a push or a pull. pull that causes objects to accelerate. Unbalanced forces cause objects to accelerate.
- No differentiation of the outcome of balanced and unbalanced forces. | - Balanced forces cause objects to move at a constant speed.
- The amount of the force in the direction of the object’s motion must be greater than that of the opposing force. | - There is no need for net forces in the direction of an object’s motion. An object may move at a constant speed when the net force acting on it is zero.
- The act of setting objects in motion imparts in them a force. | - There is no need for a force that keeps objects moving. Objects can move at a constant speed without force acting on them.
- Force acquired by objects after they are set in motion keeps them moving. Therefore, moving is not considered as a natural state of objects. | - Natural state of objects can be motion. Objects keep moving until a force is acting on them.
- Force acquired by an object acts in the direction of object’s movement and stays constant throughout object’s travel. | - Inertia is not a force. It does not have amount and cannot be compared with the amount of a force.
- Objects cannot move at constant speed if two forces in opposite directions act on the object. | 

Table 4.6: Lisa’s pre-instructional and post-instructional ideas about force and one-dimensional motion.

The data from the pre- and post-instructional interviews indicate that Lisa acquired a better scientific understanding after the instructional interventions. She changed most of her alternative ideas that she held prior to the instructional interventions with scientific views of force and motion. Her acquisition of a better scientific understanding of force and motion concepts after the instructional interventions is also
seen in her scores on the pre- and post-FCI. Although Lisa could only answer 8 items of the FCI correctly before the instructional interventions, she responded correctly to the 27 items of the FCI after the instructional interventions.

**Lisa’s Metaconceptual Processes about Force and One-Dimensional Motion**

The aim of this section is to describe Lisa’s metaconceptual processes related to force and one-dimensional motion. Before unpacking Lisa’s metaconceptual processes, it is worth noting that throughout most of the group discussions, Lisa and David worked in the same group. Therefore, a few of the excerpts provided as evidence for Lisa’s use of metaconceptual processes are the same as those provided in the section devoted to David’s metaconceptual processes. Although their content is the same, the focus of those excerpts in this section is the content and the nature of Lisa’s metaconceptual processes.

Like David, as Lisa participated in various activities, she engaged in several types of metaconceptual processes. In terms of the types of metaconceptual processes, Lisa engaged in the same type of metaconceptual processes that were displayed by David. Since the content of the alternative ideas they brought to the classroom setting was different, the science content of her metaconceptual processes was unsurprisingly different from the science content of David’s metaconceptual processes, although there were also similarities. Even though they engaged in the same types of metaconceptual processes, in a particular context there were individual differences in their engagement in metaconceptual processes in terms of the level of sophistication. Having force and one-dimensional motion as the main content area, her metaconceptual processes are described
within three conceptual subtopics: definition of force, Newton’s First, and relative amount of forces to move an object

*Lisa’s Metaconceptual Processes about the Definition of Force.* Prior to the instructional interventions, Lisa was not able to identify acceleration as the outcome of force, but rather she associated force with any kinds of motion. Throughout the instructional activities, Lisa became aware of this idea as she attempted to define force concept and identify the relationship between force and the movement of objects.

At the beginning of the instructional interventions, as groups of students drew posters about force, Lisa became aware of her understanding of force (see Activity 1 in Appendix C). The excerpt below is taken from poster drawing activity.

Brandon: Alright, David, force.
David: Yeah, force.
Brandon: What do you think Kevin?
Lisa: Like energy being applied to an object.
David: Well, Yeah. So what you can see is like a symbolic force.
Brandon: Energy applied to an object in a direction or not?
Lisa: Yeah, in the direction.
David: Direction.
Brandon: Energy applied to an object in a direction. Write that down. (Excerpt from poster drawing activity, activity 1)

As the excerpt above shows, Lisa engaged in first-order metaconceptual awareness of her ideas about force by making an explicit definition of it. Similar to David, who associated force with kinetic energy, Lisa defined force as energy applied to an object. In doing so, she associated force with energy, which is an entity that can be transferred from one object to another. During the same activity, Lisa explicitly showed that she did not only associate force with energy, but also with motion.
Lisa: Okay, attributes used to describe force.
David: Intangible. It’s not something you can hold in your hand necessarily.
Lisa: Motion.
Brandon: Motion.
David: Motion, magnitude. (Excerpt from poster drawing activity, activity 1)

In her attempt to list the attributes of force, Lisa explicitly identified motion as an
attribute of force. In doing so, she revealed her idea regarding her association of force
with motion rather than acceleration (first-order metaconceptual awareness of her idea).

During the class discussion, which took place after group discussion about activity 2 (see
Activity 2 in Appendix C), Lisa explicitly restated her idea that force caused objects to
move. Below is the excerpt taken from the class discussion about activity 2.

Teacher: Is there any relationship between the forces acting on the object on its
way from point A to B? Is there any relationship between the forces
acting on the object and its motion?
Lisa: Yes.
Teacher: What would they be? So what relationships are there between forces
and motion?
Lisa: Forces create motion. (Excerpt from class discussion after activity 2)

In activity 2 (part A), after students discussed in groups the forces acting on a book
pushed by exerting a constant force, they were requested to come up with a relationship
between force and motion. When the teacher asked students whether there were any
relationships between forces acting on objects and their motion, Lisa did not distinguish
acceleration as the outcome of force from other kinds of motion but, rather, she made an
explicit reference to her idea that “forces create motion” (first-order metaconceptual
awareness of her idea).

At the end of the instructional activities, when students were given their initial
posters to make change in the ideas presented in the poster, Lisa displayed evidence for
her ability to become aware of her current understanding of force and monitoring changes in her ideas regarding the definition of force. The excerpt below is taken from students’ dialogue prompted by poster revisiting activity (see Activity 12 in Appendix C).

David: Our original definition was energy applied in a direction to an object. We should change it to…
Lisa: Definition of force…
David: Interaction in a direction?
Lisa: Yeah, interaction that can cause acceleration.
David: Or change in the state of motion.
Kevin: Interaction between objects that can cause a change in the objects’ current state of motion.
Lisa: Okay. We change energy to interaction that can…
[students chose markers to make changes in their original poster]
David: Okay. We change energy to interaction okay not that causes but that can cause a change in the objects’ current state of motion. (Excerpt from poster revisiting activity, activity 12)

As the above excerpt indicates, at the end of the instructional interventions, Lisa no longer associated force with any kinds of motion but, rather she was able to differentiate acceleration as the outcome of force from other kinds of motion (“Yeah, interaction that can cause acceleration.”). Like David, Lisa was not only aware of her current definition of force, but she also displayed evidence for her ability to monitor changes in her initial definition of force (“Okay. We change energy to interaction that can…”).

In summary, Lisa became aware of her previously identified alternative idea that force caused objects to move as she participated in the metaconceptual teaching activities. Lisa also made reference to her association of force with energy. At the end of the instructional interventions, she monitored the changes in her definition of force from considering it as energy to interaction that changed objects’ current state of motion.
Lisa’s Metaconceptual Processes about the Relative Amount of Forces Needed to Move an Object. The aim of this section is to describe Lisa’s metaconceptual processes regarding her ideas about the amount of forces needed to keep objects moving. Before the instructional interventions began, Lisa could not differentiate the outcome of balanced and unbalanced forces. Like David, Lisa believed that the force in the direction of the object’s motion had to be greater than the force acting in the opposite direction, even if the object was moving at a constant speed. Lisa displayed evidence for her engagement in first-order metaconceptual awareness of this idea in her journal entry written prior to the group discussion prompted by the A part of activity 2 (see Activity 2 in Appendix C). In activity 2, students were asked to push a book on the table by exerting a constant push. Before group discussion, students were asked to make a journal entry that explained the forces acting on the book. Below is Lisa’s journal entry written in response to questions provided in activity 2.

[The forces acting on the book are:] The push [force from hand], friction, air forces, gravity.  
[Direction of the forces:] Push: forward, friction: backward. 
The [amount of the] push is the same or constant overcoming friction. 
It [motion of the book] is constant because push is constant and so is friction. 
(Journal entry before group discussion in response to part A of activity 2)

In the above excerpt, Lisa described her ideas regarding the type, direction, and amount of forces. Although she claimed that the book was moving at a constant speed (“It [motion of the book] is constant…”), she explicitly stated that the force exerted in the direction of the book’s motion was greater than friction (“The [amount of the] push is the same or constant overcoming friction.”) (first-order metaconceptual awareness of her idea). For Lisa, the book moved at a constant speed because constant forces were acting
on it (“It [motion of the book] is constant because push is constant and so is friction.”) (first-order metaconceptual awareness of her idea). She attributed the steadiness of the book’s speed to the constant forces rather than the equality of forces acting on the book.

After group and class discussion regarding activity 2, when students were asked to write journals in response to journal prompt 2 (see journal prompt 2 in Appendix C), Lisa displayed evidence for another type of metaconceptual awareness. In journal prompt 2, students were asked to write about situations in which their ideas did not work and whether they found any attractive ideas during group and class discussions. Below is an extract taken from Lisa’s journal entry.

Situations where there is no friction will not have the same results as this experiment. Also, situations where there is no gravity will result in different observations…. Since I agreed with most things I wasn’t attracted to different ideas. I don’t see my limitations of these ideas but I wouldn’t be surprised if there are some. These situations are the only one I can think of. (Journal entry written in response to journal prompt 2 given after activity 2)

In the above extract of Lisa’s journal entry, she displayed her ability to become aware of a context in which exertion of a constant force on the object would result in differences in the motion of the object. On a surface with friction, she thought that the object moved at a constant speed because of the constant forces (see evidence for this idea of Lisa in her previous journal entry). She recognized that on a frictionless surface exertion of a constant force on the object would cause a different type of motion other than constant movement. (“Situations where there is no friction will not have the same results as this experiment.”). In doing so, Lisa engaged in first-order metaconceptual awareness of contextual differences between the motion of objects on frictionless surface and on a surface with friction. Although she recognized that the motion of the object would be
different on a frictionless surface when a constant force acted on it, she did not display any evidence for noticing that her idea (constant force caused an object move at constant speed) was not applicable to the situations she was aware of.

Lisa claimed that she neither recognized “attractive” ideas nor found any limitation of her own ideas during the group or class discussions (“…I wasn’t attracted to different ideas. I don’t see my limitations of these ideas…”). It is clear that, for Lisa, her own ideas about the forces acting on the book were still plausible to her. She engaged in metaconceptual evaluation in the form of reflecting on the plausibility of her own ideas. Lisa’s engagement in metaconceptual evaluation was limited to reflecting on the status of her own idea. She neither compared the status of her idea with another competing idea nor provided any justifications for her idea. Although she acknowledged that her ideas might have some limitations (“I don’t see my limitations of these ideas but I wouldn’t be surprised if there are some.”), she did not show any sign of changing her ideas at this point.

After the teacher explained the outcome of balanced and unbalanced forces, like David, Lisa displayed evidence that she acquired a scientific understanding of the comparable amount of forces required for constant motion and acceleration. One of the activities that provided Lisa with the opportunity of becoming aware of her ideas regarding balanced and unbalanced forces was the concept mapping activity (see Appendix C). After drawing concept maps, students were asked to explain their maps to other students in their groups. The excerpt below is taken from students’ conversation that took place when students in Lisa’s group described their concept maps to each other.

Laura: Ok, balanced force can be constant …
Matt: Or no motion.
Lisa: Or at rest.
Matt: No motion, at rest, Fnet equals to zero.
Lisa: I said at rest was no motion.
Laura: I put constant speed having a net force is zero.
Matt: Constant speed is motion.
Lisa: No, constant speed is both balanced and no force.
Matt: Right.
Lisa: Alright. Because…
Laura: Right.
Matt: No force is either at rest or like drifting, like inertia.
Laura: But a constant speed needs to be under motion too because it’s moving at a constant speed, right?
Lisa: Yeah.
Ally: Ok, for motion -under balanced forces I have motion or unbalanced I have motion, constant speed, deceleration, acceleration. Under acceleration I have net forces greater than zero.
Lisa: Unbalanced forces?
Ally: Oh, Yeah. Yeah.
Matt: There shouldn’t be constant speed under unbalanced, right?
Ally: Yeah, well, it’s unbalanced, but under motion, if something is moving it can be moving at a constant rate.
Lisa: But if it’s unbalanced you can’t have it at a constant speed. It’s got to be acceleration.
Matt: Or deceleration.
Ally: But no, if I put it…
Lisa: We put it in as a motion, not as an unbalanced force.
Ally: Right, I put it in as a motion, not an unbalanced force. (Excerpt from students’ description of their concept maps to each other)

In the above excerpt, Lisa displayed evidence for her engagement in first-order metaconceptual awareness of her ideas about the outcome of balanced and unbalanced forces. In contrast to a previous alternative idea that the force in the direction of constant motion had to be greater than the force in the opposite direction, she made reference to an idea that was consistent with the scientific view. Lisa did not think that there had to be net forces in the direction of an object’s constant motion anymore, but rather she accommodated the scientific view that balanced forces or no forces caused an object to move at constant speed (“No, constant speed is both balanced and no force.”). Lisa was
Lisa not only able to make her idea regarding the effect of balanced forces on objects explicit, but she was also able to differentiate the outcome of balanced and unbalanced forces. In response to her group mate’s idea that unbalanced forces caused objects to move at constant speed, Lisa revealed her view that unbalanced forces did not cause objects to move at constant speed but, rather, they caused them to accelerate. (“But if it’s unbalanced you can’t have it at a constant speed. It’s got to be acceleration.”). Throughout the concept mapping activity, Lisa engaged in a metaconceptual process in which she recognized her existing ideas regarding the relationships among conceptual entities. Since she made reference to her existing ideas, this process is not qualitatively different from first-order metaconceptual awareness.

When students were asked to make a journal entry in which they group similar situations (different situations were provided in a table along with journal prompt 11) and examine the consistency of their initial and current ideas for different situations (see journal prompt 11 in Appendix C), Lisa engaged in a more sophisticated metaconceptual process. Below is an extract taken from her journal entry.

Another division is constant or increasing velocity. Before I treated them the same, I thought you had to have unbalanced forces for constant speed and acceleration. But now I know the difference, i.e., balanced forces or no forces cause constant velocity and unbalanced forces cause acceleration or deceleration. (Excerpt from journal entry written in response to journal prompt 11).

In the excerpt above Lisa showed evidence for her engagement in an impressive multifaceted metaconceptual process about her ideas regarding balanced and unbalanced forces. She grouped her initial and current ideas in terms of the type of objects’ motion, constant motion, and acceleration (“Another division is constant or increasing velocity.”). She was not only aware of her initial ideas about the amount of forces needed for objects’
motion, but she was also able to compare her initial ideas across the situations where objects were moving at a constant speed and increasing speed (“Another division is constant or increasing velocity. Before I treated them the same, I thought you had to have unbalanced forces for constant speed and acceleration.”). She recognized that she held the same idea for situations where the object was moving at a constant speed and at increasing speed. It is clear that she compared her initial ideas across different contexts. In doing so, she engaged in second-order awareness of contextual differences. Unlike David, who compared his initial idea of residual force across similar contexts (motion of a surface with friction vs. motion in the air in the upward direction) where both contexts had a common variable (force in the opposite direction), Lisa was able to compare her ideas across situations (object moving at constant speed vs. increasing speed) which were different in terms of the type of the motion. Since the amount of forces required to move an object changes with the type of the object’s motion, Lisa was able to detect her incorrect use of the same idea to explain different situations.

Lisa was not only aware of her initial ideas, but she also displayed evidence for her engagement in monitoring changes in ideas regarding the outcome of balanced and unbalanced forces. She was able to compare her initial ideas with her current ideas. (“… I thought you had to have unbalanced forces for constant speed and acceleration. But now I know the difference, i.e., balanced forces or no forces cause constant velocity and unbalanced forces cause acceleration or deceleration.”). Previously, Lisa believed that there was a need for unbalanced forces to keep the object moving at a constant speed or increasing speed. At the time of making her journal entry, she knew that balanced forces
caused objects to move at a constant speed, and unbalanced forces caused objects to accelerate and decelerate.

Collectively, as Lisa participated in the instructional activities, she became aware of her alternative idea that force in the direction of an object’s constant motion had to be greater than the force in the opposite direction, and an object moved at a constant speed due to the constant forces acting on it. Although she recognized that motion of an object on frictionless surface and on a surface with friction would be different when constant forces acted on it, she did not recognize that her idea regarding to her association of constant force and constant motion was not applicable to the situations she was aware of. After the teacher introduced the outcome of the balanced and unbalanced forces, Lisa monitored the changes in her alternative idea that unbalanced forces were required for constant motion. She was aware that she held the same idea to explain the amount of forces acting on objects moving at a constant speed and increasing speed.

Lisa’s Metaconceptual Processes about Newton’s First Law. Prior to the instructional interventions, Lisa believed that objects acquired a force after they were set in motion. For her, the acquired force acting in the direction of the motion kept the object moving. Therefore, she did not consider motion at constant speed as a natural state of being. Throughout several instructional activities, Lisa engaged in various types of metaconceptual processes related to her idea of acquired force.

Lisa made explicit reference to her idea about the acquired force in the direction of object’s motion in the journal written before group discussion about activity 2. In the B part of activity 2, students were requested to identify forces acting on a moving book
after it was set in motion by a strong push (see Activity 2 in Appendix C). Below is the excerpt taken from Lisa’s journal entry related to the part B of activity 2.

- Force of the push, friction, air forces and gravity.
- The force of the push is a force stronger than friction. Later as the book slows, friction is stronger.
- The push is forward, the friction is backward, air forces are all around and gravity is downward.
- The item slows down, decreasing in speed.
- The motion is slowed by friction while the force of the push continues to have the book move forward until friction takes over and the book rests. (Journal entry written in response to the B part of activity 2)

In the above excerpt, Lisa explicitly articulated her idea that the force applied to push the book on the table was still acting on it until it became at rest. In this journal entry, her metaconceptual process did not go beyond first-order metaconceptual awareness of her existing ideas. Although the hand of the person who pushed the book was no longer in touch with the book, for Lisa, the force from the hand was still acting on the book as it moved. She believed that the acquired force kept the book moving in the forward direction. (“The motion is slowed by friction while the force of the push continues to have the book move forward until friction takes over and the book rests.”). It is clear that, for her, force applied to push the book transferred from the hand to the book and became an internal property of the book. Although Lisa did not explicitly state, she considered force as an entity that can be transferred from the agent to the object.

In a journal entry, which Lisa wrote before group debate prompted by activity 3, she made explicit reference to her ontological presuppositions about force and objects’ natural state of being. In activity 3, students were asked to choose between two alternatives about forces acting on an object moving on a frictionless surface (see Activity 3 in Appendix C). Students were requested to defend one idea against the other.
Lisa chose alternative B, which involved the idea that there was a force acting on the object in the direction of its motion on frictionless surface. Below is Lisa’s journal entry written prior to group debate.

I think there is force acting on the object in the direction of its motion. Reasons:
• If it collides its force will be transferred, therefore it must still have force when it collides.
• The object is still moving. An object will not move without force.
The motion of the object would be horizontal. On a frictionless surface the object will be slowed down. The forces are the same except for friction. The reason for this is that only one variable has been changed. Other forces are controlled. (Journal entry written in response to activity 3)

For Lisa, there was force acting in the direction of object’s motion as it moved on frictionless surface. Lisa did not only make reference to this idea, but she also engaged in metaconceptual evaluation as she provided justifications for her idea. As she defended her idea, she justified her idea by making reference to her experiences and ontological presuppositions about force and natural state of objects. Lisa recognized her ontological presupposition that objects could not move without force acting on them. For her, motion was not a natural state of objects (“The object is still moving. An object will not move without force”). Lisa also became aware of her ontological presupposition about the nature of forces. She referred to an experience in which a moving object struck another object that was at rest, and after the collision, the moving object stopped and the object at rest started moving. (“If it collides, its force will be transferred therefore it must still have force when it collides.”). Since, for her, the object could not move without a force acting on it, force from the moving object had to be transferred to the object at rest to start its movement. It is obvious that in an attempt to justify her idea, Lisa became aware
of her ontological presupposition that force was an entity that was transferred from one object to another (first-order metaconceptual awareness of ontological presupposition).

During the group debate prompted by activity 3, Lisa displayed evidence for her engagement in other types of metaconceptual process, such as monitoring ideas of other people, metaconceptual evaluation in the form of making reference to the plausibility of an idea, and first-order metaconceptual awareness of what she does not know. Below is an extract taken from students’ dialogues, which took place during group debate.

Lisa: Are you A or B?
David: I'm A.
Connor: I'm A. No, wait, I'm B. I'm B. Can I go first? I said that there's horizontal force acting upon the object. I think that the hand, you still exert force over the object even though you're not still physically touching it. It's moving because of the initial force that you applied. That was my answer.
David: This is David and I am A. This just makes more sense. I think that the force acting is gone after your hand leaves the object. It's still moving. Friction slows it down. If there were friction the object would slow down. If there is no friction there is nothing to slow it down. It wouldn't have to counteract any kind of force. It's like a hockey puck it just moves in a direction. It doesn't counter anything.
Lisa: You're saying that after the push there is no force acting upon it?
David: There's this momentum, but if it was on a certain friction it wouldn't move. It would slow down because of friction. It almost keeps going because of the lack of friction.
Connor: I cannot follow what you said. What do you think about when something collides?
David: See that's the part that I'm not sure about. Because I mean it might depend on the mass of the objects that collide, or the weight, or what. If there is friction and if you just pushed it, it would eventually slow down and stop because friction acts upon it. Up to now we've just defined constant forces produces constant speed. But on a frictionless surface if you push it, it keeps going. There is nothing to slow it down.
Connor: But, you know, the initial force from your hand and like if friction is slowing it down the force from your hand is going to ...
Lisa: Yeah, the friction is overcoming the force from your hand more and more. But I did see the point of lack of force. That makes
sense too. It's really not intelligent if you don't have enough information. I'm really interested in that conversation. It's hard. We can't really back it up.

David: Yeah, because we haven't done any kind of I mean ... Well, I've been trying to think of an example. But if a hockey puck, if it's just running across the rink, whether or not it has any hand pushing it across the rink, it keeps going. Yeah, if it runs into a marble, it's still gonna push the marble, but if it runs into the wall of the rink, it's not going to do anything. But it still has that momentum

Lisa: Yeah, is momentum a force?
David: I don't know, but it's what we've been debating.
Lisa: Yeah, what's the definition of force?
David: Yeah, we don't even know what the definition of force is, so we can't really say whether the momentum is a force or not

Connor: I think the momentum is where you ram your hand back and then shove it.

David: Yeah, I'm just trying to decide what exactly is momentum? But if it is moving is that a force or momentum?

Lisa: Yeah, momentum is kind of like the aftershock of force. But you don't know if it is force.

David: Right, exactly. I suppose this whole thing depends on the fact that none of us really know what force is. But I don't really know what it [momentum] is, but I think it is there.

Lisa: Yeah, it's just a guess. (Excerpt from group debate in response to activity 3)

In the excerpt above, Lisa revealed her idea that on a surface with friction, force acquired from the hand was overcame by friction as the object slowed down (“Yeah, the friction is overcoming the force from your hand more and more.”) (first-order metaconceptual awareness of her idea). Lisa also displayed evidence for her ability to monitor David’s idea that no force was acting on the object as it moved (“But I did see the point of lack of force.”). Lisa reflected on the plausibility of David’s idea by saying that it made sense for her (“That makes sense too.”) (metaconceptual evaluation). However, Lisa did not provide any reasons or justifications for why she found David’s idea plausible.

Throughout the discussion, although David engaged in metaconceptual evaluation by
providing justifications for the idea he chose based on his experiences and knowledge about the motion of objects on frictionless surface, Lisa’s engagement in metaconceptual evaluation could not go beyond commenting on the plausibility of David’s idea. Lisa recognized that she did not have adequate knowledge to metaconceptually evaluate one idea against the other (‘It's really not intelligent if you don't have enough information. I'm really interested in that conversation. It's hard. We can't really back it up.”). Her realization of not possessing adequate information made her pay attention to the content of their discussion. Later in the conversation, Lisa recognized that she did not know the definition of momentum and force (“Yeah, is momentum a force? … Yeah, what's the definition of force?”) (first-order metaconceptual awareness of what she does not know). Although Lisa defined momentum as an “aftershock force,” she did not know whether it is considered as a force or not (“Yeah, momentum is kind of like the aftershock of force. But you don't know if it is force.”).

After group debate, students wrote in their journals about the ideas they discussed during group debate and class discussion. In a journal entry written in response to journal prompt 3, Lisa stated that she did not change her ideas after group and class discussions (see journal prompt 3 in Appendix C). Lisa’s journal entry is below.

I understood what my partner was mostly saying. I did not understand his explanation of how a colliding object proves his stance. He does not believe that a force is acting on it because the hand is gone. I have faith that there is something that keeps the object moving (force). To argue intelligently we need to know what the definition of force is. I didn’t change my mind because I feel my point has more proof behind it than my partner’s point had. (Journal entry written in response to journal prompt 3, after activity 3)
The excerpt above shows that Lisa successfully monitored David’s idea that there was no force acting on the object as it moved on a frictionless surface (“He does not believe that a force is acting on it because the hand is gone.”). She also monitored her understanding of David’s idea. Although Lisa understood the content of David’s idea, she did not understand how David’s idea explained the forces acting on colliding objects (“I did not understand his explanation of how a colliding object proves his stance.”). Lisa not only engaged in monitoring changes in her ideas, but she also metaconceptual evaluated her own idea against David’s idea. For her, her own idea was more plausible than David’s idea because her idea about the force transfer during the collision of objects served as a proof for the validity of her idea (“I have faith that there is something that keeps the object moving (force). …I didn’t change my mind because I feel my point has more proof behind it then my partners point had”). In other words, although she found David’s idea intelligible, the same idea was not plausible to her due to the inability of David’s idea to explain the motion of colliding objects. At the time she made the above journal entry, she did not change her idea that force acquired from the agent kept the object moving.

After the tasks related to activity 3 were completed, the teacher introduced Newton’s First Law of inertia. In the journal entry written in response to journal prompt 4, Lisa displayed evidence that she changed her idea of acquired force with the scientifically accepted view of inertia.

Yes, I understand that objects in motion remain in motion. I know this because I can use examples to support my thoughts. I believe everything. The difference in understanding is all a “word-game.” I agree with everything in my thoughts. The words I used to express my ideas were defined differently than how I used them. The way Newton’s Law and the definition of words [inertia] put my views into a clearer nature. It makes my ideas look nicer, neater, and is easier to work with.
The one idea that changed was really an adjustment. I said a force is motion and therefore an object after being pushed still has my definition of force. If you define force as an interaction my statement is wrong. It’s all a word game. What I thought of as included in my definition of force, Newton called inertia. Newton’s definitions and laws better explain motion. It divides my definition of force into different groups based on what happens to the objects. My [current] definition includes:

- **Inertia**: a constant velocity
- **Force**: an acceleration (unbalanced)

I didn’t define what these two ideas individually did. (Journal entry written in response to journal prompt 4)

In the above journal entry, Lisa used sophisticated metaconceptual processes, such as monitoring her understanding of ideas, second-order awareness of what she did not know before, monitoring changes in her ideas and metaconceptual evaluation. She was able to successfully monitor her understanding of Newton’s First Law of Inertia. Unlike David, her statement of the law was consistent with the scientific view (“Yes, I understand that objects in motion remain in motion.”). For her, using examples was a way to check her understanding of the law (“I know this because I can use examples to support my thoughts.”).

In the above excerpt, Lisa engaged in a very impressive metaconceptual process in the form of monitoring of changes in her ideas. For Lisa, the changes in her ideas were a “word-game.” She was aware that she initially used the word “force” to define her idea of objects’ motion that they have after being exerted by a force (“I said a force is motion and therefore an object after being pushed still has my definition of force”). In doing so, she engaged in second-order metaconceptual awareness of her initial ideas. Lisa was able to monitor that her initial idea of force (acquired force) was defined differently by scientists (“The words I used to express my ideas were defined differently than how I
Like David, she was aware that she considered inertia as a force. She monitored the consistency of her initial idea with the Newtonian view of inertia as she stated that her idea of acquired force was defined as inertia by Newton. (“It’s all a word game. What I thought of as included in my definition of force, Newton called inertia.”).

Lisa was also able to make reference to her current understanding of force and inertia. Unlike David, she differentiated the outcome of inertia and force. She acquired the scientific view that objects moved at a constant speed due to their inertia, and they accelerated as a result of unbalanced forces. Lisa realized that she could not make this differentiation before (“I didn’t define what these two ideas individually did.”).

Lisa also engaged in metaconceptual evaluation as she made an epistemological comparison between her previous ideas and Newton’s Laws. For Lisa, the ideas presented in Newton’s Laws were clearer and easier to use (“The way Newton’s Law and the definition of words [inertia] put my views into a clearer nature. It makes my ideas look nicer, neater, and is easier to work with.”). Another criterion that served as a basis for metaconceptual evaluation was the ability of Newton’s Laws to distinguish fundamental concepts such as inertia and force based on the type of motion of the objects. For Lisa, while her previous understanding of force could not differentiate constant speed and acceleration as the outcome of force, Newton’s Laws stated that the objects accelerated because of forces being acted upon them and they continued to move at a constant speed due their inertia (“Newton’s definitions and laws better explain motion. It divides my definition of force into different groups based on what happens to the objects.”).

Lisa’s ability to recognize the ontological distinction between inertia and force was also seen in her journal entries related to activity 7 (see Activity 7 in Appendix C). In
activity 7, students were asked to choose one of six pictorial representations that depicted the forces acting on a ball tossed up as it was rising. Having acquired the scientific view of inertia, in her pre journal entry, Lisa identified gravity as the only force acting on the ball throughout its travel (“Gravity is the only force acting on the ball.”). In the same journal entry Lisa made reference to the ontological distinction between inertia and force (“Inertia is a property, tendency to maintain its current motion. Force: interaction and ability to accelerate.”). Unlike David, Lisa was able to refer to the ontological characteristics of force and inertia. While Lisa considered inertia as a property of objects, she defined force as an interaction. In doing so, Lisa engaged in first-order metaconceptual awareness of her ontological presuppositions. Lisa was able to make a similar distinction in her journal entry written in response to journal prompt 8 related to activity 7 (see journal prompt 8 in Appendix C). She explicitly stated that she did not consider inertia as a force and in the force diagram only gravity had to be shown (“No force is acting upward. Inertia is not a force. Gravity is the only force acting on the ball. … In a force diagram only gravity should be shown”).

Lisa’s ability to monitor changes in her ideas about Newton’s First Law of Inertia was seen in her journal entry written in response to journal prompt 11 (see journal prompt 11 in Appendix C).

The main difference in my initial and current ideas is the idea that inertia is a force. I said that there was a force if the object was moving even the applied force was long gone. (Excerpt from journal entry written in response to journal prompt 11)

Lisa was capable of monitoring that she changed her initial idea of acquired force with the concept of inertia. She was aware that her initial definition of acquired force was
scientifically defined as inertia. As she monitored the changes in her idea, she made reference to her initial idea about acquired force (“I said that there was a force if the object was moving even the applied force was long gone.”).

To sum up, Lisa became aware of her idea that objects acquired force after they were set in motion and that force was necessary to keep the objects moving. In an attempt to defend this idea, she drew on an experience about colliding objects and made reference to her ontological presuppositions that objects could not move without force acting on them and force was a transferable entity. In a group discussion, although she found David’s idea that force was not acting on an object sliding on a frictionless surface plausible, she could not provide any reasons and justification for why that idea was plausible to her. In a journal entry about that discussion, although she monitored her understanding of the content of David’s idea, she stated that she did not change her idea, since David’s idea could not explain the motion of colliding objects. She realized that she did not have enough information to make correct claims about the validity of ideas. She recognized that she did not know force and momentum. Her realization of inadequate knowledge caused her to pay attention to the content of discussion. After the teacher introduced Newton’s First Law, Lisa was aware that she initially considered inertia as acquired force. She monitored the inconsistency between her idea of acquired force and Newton’s notion of inertia. Unlike David, Lisa was able to distinguish the outcome of force and inertia (force causes objects to accelerate and objects move at a constant speed due to their inertia) and became aware of the ontological characteristics of force and inertia (inertia is a property; force is an interaction). Lisa also engaged in metaconceptual evaluation in the form of reflecting on the usefulness of Newton’s Laws. For her, while
Newton’s definition of inertia and force made a distinction in the objects types of motion (inertia caused objects to move at a constant speed and force caused objects to accelerate), her initial understanding of force could make such a differentiation.

**Summary of Lisa’s Metaconceptual Processes about Force and One-Dimensional Motion**

Throughout the instructional activities related to force and one-dimensional motion, like David, Lisa displayed evidence for her engagement in various types of metaconceptual processes. At various points during journal writing, group and class discussions, Lisa become aware of her current and previous ideas. She was able to make explicit reference to many of her existing ideas identified prior to the instructional interventions. The excerpts provided in the sections related to Lisa’s metaconceptual processes show Lisa’s engagement in the first-order metaconceptual awareness of the following alternative ideas: (a) force is energy applied to an object in a direction, (b) forces create motion, (c) force in the direction of object’s constant motion is greater than the force acting in the opposite direction, (d) objects move at constant speed because constant forces are acting on them, (e) the force acquired from the agent still acts on the object even though the object lost its contact with the agent, (f) the acquired force acting in the direction of the object’s motion keeps the object moving.

Similar to David, Lisa became aware of her experiences and ontological presuppositions either to provide explanation for a situation or to justify competing ideas as she evaluated them. For example, as Lisa defended her idea, she became aware of her ontological presuppositions regarding the natural state of objects and nature of force. For Lisa, objects’ motion needed explanation. She made reference to her ontological
presupposition that objects could not move without force acting on them. She was also aware that she considered force as an entity that could be transferred from one object to another. After she acquired a scientific understanding of inertia, like David, Lisa could make an ontological distinction between force and inertia. Although both students explicitly stated that they did not consider inertia as a force, Lisa was able to explicitly distinguish the ontological characteristics of inertia and force. She was aware that she considered inertia as a property and force as an interaction.

In addition to her first-order metaconceptual awareness of her ontological presuppositions, Lisa displayed evidence for her ability to make reference to contextual differences. She recognized that the motion of objects on a frictionless surface would be different from their motion on a surface with friction. Lisa’s ability to become aware of the contextual difference went beyond first-order level of awareness. She was also able to compare her use of initial ideas in two contexts, where objects were moving at a constant speed and at increasing speed. She was aware that she held the same idea (force in the direction of the object’s motion had to be greater than the force in the opposite direction) for both situations. Unlike David, who compared his initial idea of residual force in similar situations that shared the same variable (force in the opposite direction), Lisa was able to compare her initial idea situations that differed in terms of the amount of forces needed to move an object.

Lisa’s engagement in second-order awareness was seen when she made reference to her idea regarding the acquired force. She recognized her initial belief that the force applied by an agent was still acting on the object as it moved even though the object was no longer in touch in the agent. Her awareness of her initial ideas was also seen when her
group revisited their poster drawn at the beginning of the instructional interventions. She recognized that she initially defined force as energy applied in a direction.

As Lisa participated in the instructional activities, she became aware of the conceptual entities that she did not know. For example, while she defended her idea about whether force was acting on an object on a frictionless surface, she realized that she did not know the definition of force and momentum. Her realization of what she did not know caused her to pay attention to the content of the discussion. Her awareness of what she did not know was not limited to first-order level of awareness. After she acquired a scientific view about inertia, she realized that she did not know the difference between the types object’s motion resulted from unbalanced forces and inertia (objects continue to move at a constant speed due to their inertia and they accelerate as a result of unbalanced forces acting on them).

Throughout the group discussions, Lisa was not only aware of her own idea, but she displayed evidence that she could monitor her group mate’s ideas. For example, she could correctly restate David’s idea that there was no need for a force to keep objects moving. She was also able to monitor the inconsistency between her idea of acquired force with Newtonian view of inertia.

Another type of metaconceptual monitoring process that Lisa was able to engage in was her monitoring of her understanding of ideas. For example, she claimed that she understood Newton’s First Law. Her statement of Newton’s First Law in her own word shows that she acquired a scientific understanding of the inertia concept. For Lisa, one way of checking her understanding was using her idea in different examples.
Lisa’s ability to monitor the changes in her ideas was seen in different conceptual topics. For example, she recognized that she initially did not differentiate the amount of forces acting on objects that were accelerating and moving at a constant speed. Lisa displayed evidence for monitoring changes in her ideas when she made reference to her current idea that unbalanced forces caused objects to accelerate, and balanced forces caused objects to move at a constant speed. Lisa was also able to monitor the change in her initial idea of acquired force with inertia. For her, the change in her initial idea of acquired force with inertia was a “word-game.” She was aware that her previous idea of acquired force was defined as inertia by scientists. Being aware of the change in her initial idea of acquired force with inertia and being able to differentiate the ontological characteristics of force and inertia, Lisa showed that she monitored the ontological shift in her ideas when she made an ontological distinction between force and inertia (force is interaction, inertia is a property).

Metaconceptual evaluation was another qualitatively different metaconceptual process for which Lisa displayed evidence. At various points during group discussions and in her journal entries, Lisa reflected on the plausibility of her ideas and ideas of other students, and she commented on the relative usefulness of Newton’s Laws compared to her own ideas. For example, in a journal entry about forces acting on an object moving at a constant speed as a result of being pushed by hand, she maintained that she neither found any attractive ideas nor saw any limitations of her own idea during group and class discussions. Her statements indicated that her ideas were still plausible to her. At another point, Lisa maintained that she retained her existing idea about the need for forces to keep objects moving on a frictionless surface. She explained her reasoning behind her idea
with an example about colliding objects. For her, a stationary object started to move as a result of a collision with a moving object due to the transfer of force from the moving object to stationary object. As she maintained that David’s idea (no force is necessary to keep objects moving) could not explain the motion of colliding objects and her idea had more proof, she engaged in metaconceptual evaluation in the form of making comparative judgmental decisions about her own idea and David’s idea. Lisa also engaged in less sophisticated form of metaconceptual evaluation, as she commented on the plausibility of an idea without providing any reasons or justifications. While Lisa defended one idea against another, she realized that she did not posses enough information to make a correct judgmental decision about ideas. For example, she realized that she needed to know the definition of force to argue about ideas. Lisa was also able to make an epistemological comparison between her initial idea of acquired force and Newton’s Laws. For Lisa, Newton’s Laws are clearer and easier to work with than her own ideas. Compared to her initial idea of acquired force, for Lisa, Newton’s definition of force and inertia could distinguish the types of motion (constant speed due to inertia vs. acceleration due to unbalanced forces), while her initial understanding of force could not make such as a differentiation.

*Types of Metaconceptual Processes*

In the previous section, metaconceptual processes of two students were portrayed with an emphasis on the conceptual content of those processes. In doing so, each student’s conceptual ideas before and after the instructional interventions were identified, and their metaconceptual processes related to those ideas were described along with
providing the context of the instructional activities. The aim of this section is to describe each type of metaconceptual process by providing exemplary excerpts taken from three students. In this section, data collected from Kelsey are also used, along with David and Lisa’s data, in order to add diversity to the examples provided for each type of metaconceptual processes. No detailed description of the conceptual content of metaconceptual processes and the context of instructional activities is provided but, rather, the trends in (if any) and the interdependent and the multifaceted nature of each type of metaconceptual process are explained. In a previous section, students’ metaconceptual processes were described within the content area of force and one-dimensional motion. In this section, however, each type of metaconceptual process is explained by providing examples from all content areas covered by the designed instructional activities (e.g., definition of force, Newton’s First Law, Newton’s Second Law, Newton’s Third Law, friction, projectile motion, gravity, and circular motion).

First-Order Metaconceptual Awareness

In this study, evidence for two types of metaconceptual awareness was found in the data: (a) first-order metaconceptual awareness, and (b) second-order metaconceptual awareness. In both types of metaconceptual processes, learners make reference to conceptual ideas and elements of their conceptual ecology that they already possess or generate. The difference between first-order and second-order metaconceptual awareness lies in learners’ recognition of their current ideas and their ideas they had in the past. Unlike the metaconceptual monitoring processes, learners do not encounter new
information when they engage in metaconceptual awareness but, rather, they make their current or past ideas and elements of their conceptual ecology explicit.

First-order metaconceptual awareness is a process in which learners explicitly make reference to their existing concepts, generative or stored representations of the physical world and elements of conceptual ecology, including past experiences, ontological presuppositions, and contextual differences. Their recognition of what they do not know is also considered as first-order metaconceptual awareness. In that case the learner refers to a conceptual entity that is missing in his or her existing conceptual structure or which the learner does not know how it works in a given situation.

Throughout the instructional activities, students provided evidence for their engagement in several types of first-order metaconceptual awareness. Students not only made their idea about a given situation explicit, but they also displayed evidence for their awareness of their ontological presuppositions, the contextual variables, their experiences with the physical world, and conceptual entities that they did not know. Students in this study made their ideas for two purposes: (a) to provide explanation for a given situation in an attempt to deal with the demands of the instructional activities, and (b) to provide reasons or justifications for ideas in an attempt to evaluate the competing ideas.

Each category of first-order metaconceptual awareness is described below.

**First-order Metaconceptual Awareness of Mental Models and Ideas/Conceptions.** Learners engage in first-order metaconceptual awareness when they simply make their ideas or mental representations about physical world explicit. In this study, students provided extensive evidence for their ability to make reference to their ideas.
Instructional activities, such as group and class discussions, group debates, journal writing, and poster drawing provided students with opportunities to make reference to their ideas in the form of verbal and written comments and drawings. The sections devoted to the description of the three case studies involve numerous examples about students’ first-order metaconceptual awareness of their ideas about force and one-dimensional motion. In Table 4.7, examples from other content areas (Newton’s Third Law and projectile motion) are provided.

The first example taken from David’s journal entry involves his ideas and predictions about two situations. In an attempt to predict the results of two demonstrations (a person on a skateboard pushes another equally weighted person who is also on a skateboard; and a person on a skateboard pushes another person who is also on a skateboard and weighs more), and to explain forces acting on objects and people in the demonstrations, David was able to make his ideas explicit. In the second example, as students discussed the path of a bullet shot horizontally, Lisa and David were able to make reference to their idea that the bullet’s inertia dissipated as it was overcome by gravity.

Vosniadou and Ioannides (1998) argued that learners not only retrieve stored mental representations from their memory, but they also create generative mental models when they attempt to provide explanations of physical phenomena and make predictions about the physical world. Therefore, as learners engage in first-order metaconceptual awareness of their ideas, they either make reference to their existing ideas stored in their memory or generate “on the spot” mental representations to explain a situation. During a class discussion about learning, Lisa maintained that she did not always possess existing
Example 1

David: There are equal forces coming from student A and B. When A pushes on student B, they exert equal force. Therefore, the equal forces cancel each other out. Student A exerts a force with mass= 65 kg, and the normal force from student B with mass=65 kg equals A’s force. No movement. Now in situation C, student C definitely pushes D way, exerts a greater force with his greater mass. (Journal entry written in response to activity 10 (about Newton’s Third Law))

Example 2

Lisa: So the path is an arc and we all agree on that?
David: After it leaves the cliff there isn’t, I mean it left the gun there isn’t a force behind the bullet so just the horizontal inertia, but the gravity is still acting down on it.
David: It just seems to me that gravity would be almost overcoming the horizontal inertia, there’s nothing…it’s a force acting down on the bullet.
Brandon: Well that wouldn’t slow it down.
David: But it would make a the curve go like this. Cause now gravity is increasing the downward motion of the bullet. The path itself, the bullet’s direction doesn’t change, but the bullet…
Brandon: It’s like this, like at a very straight angle, yeah very small but on a wide scale it’d be like that.
Lisa: Could it ever go, like straight?
Brandon: Well no, gravity is acting on it even from when it’s being shot out.
David: I said that it would be eventually. I didn’t write it down, but that’s what I had in mind, that eventually it would come straight down because eventually gravity would accelerate vertical motion so much that horizontal inertia would…I don’t know if it runs out or what.
Lisa: Yeah, at some point. It may have so little that it becomes zero.
David: Yeah, right.
Lisa: Maybe it’s not possible to become zero…
David: Maybe it’s just in relation, if you look at a graph of it moves so little this way that it looks like it’s going straight.
Lisa: Yeah, it looks straight. (Excerpt from group discussion prompted by activity 8 (about projectile motion))

Table 4.7: Exemplary excerpts for first-order metaconceptual awareness of mental models and ideas/conceptions.
and stored ideas about a given situation but, rather, she sometimes generated ideas to deal
with the demands of the instructional activities.

Teacher: Do you think it is helpful to be in touch with your own ideas about a
concept before you are ready to move on and learn new ideas? I think it
is what you were comparing David. I’m not sure… To be able to find out
what you know and where the holes might be in your ideas before you
come up with new ideas.
Student: I think it is time-consuming.
Teacher: Time-consuming? Yes, it is.
Lisa: I’d rather learn scientific ideas right away before I figure out what I
think. Because sometimes you really don’t have any ideas. And then we
formed ideas and we wanted to believe in them. You forced us and you
let us think about what we would think if we actually thought about it.
And then we had to change them. I think it would be nice just to know
what we are supposed to know and what is right and just figure out what
is right. (Excerpt from class discussion)

While generative mental representations are created to provide “on the spot”
explanations when needed, stored mental representations are constructed earlier by
learners when they thought about a same or similar situation before. Although generative
mental representations are dynamic, they may contain some permanent features stored in
the long-term memory and retrieved from the long-term memory when necessary
(Vosniadou & Ioannides, 1998). Therefore, as students generate “on the spot”
explanations about a physical phenomena, they may also make reference to the stored
conceptual structures that constrain the formation of generative mental representations.

It is worth noting that explicitly revealing one’s ideas or mental models is a
prerequisite for more sophisticated metaconceptual processes, including second-order
metaconceptual awareness of initial ideas, monitoring consistency between new and
existing ideas and monitoring changes in ideas. For example, in order to make reference
to a previous idea, learners have to make that idea explicit at an earlier time. Similarly,
learners have to be aware of their existing ideas in order to be able to compare new ideas with existing ideas. In order to monitor changes in ideas, learners have to become aware of their previous and current ideas. Examples of these metacognitive processes are provided above in sections devoted to each process. It is clear that engaging in first-order metacognitive awareness of ideas is critical for learners’ engagement in other types of metacognitive processes.

No matter whether the ideas or mental representations are stored or dynamically generated, they become intact unless learners explicitly and actively think about them. In this research, through a variety of instructional activities students were facilitated to recognize the elements of their conceptual structures. For all three students, becoming aware of their own science ideas was a new learning experience. They provided the following responses when they were asked how their learning experience in this class was different from other classes:

Kelsey:  Well, thinking of my initial ideas. I’ve never been asked to think of my initial ideas. Well, I’ve done discussions before but not in this way.

Lisa:   This is one of the first times I have been asked to think about my own ideas.

David:  This is the only class. I am only taking one science class now. But I’ve taken one in my freshman year one in my sophomore years as well. In those two classes I took biology and chemistry…. There really has never been anything like this where you were forced to think about your initial ideas. It wasn’t that they were trying to hear what you were initially thought at first.

For Kelsey, Lisa, and David, this physics class had been the only class in which they were encouraged to make their own ideas explicit. It is clear that in other classes that they have taken so far they have not been asked to engage in first-order awareness of their
ideas which plays a critical role in learner’ engagement in more sophisticated metaconceptual processes.

First-order Metaconceptual Awareness of Ontological Presuppositions.

Ontological presuppositions are beliefs regarding the “kinds of entities we assume to exist and the way they are categorized” (Vosniadou & Ioannides, 1998, p.1216). According to Chi, Slotta, and Leeuw (1994), conceptual entities belong to different ontological categories. They argued that misconceptions arise when learners assign a concept to an inappropriate ontological category. For example, students frequently represent force as a kind of entity that belongs to the matter category, while in fact it belongs to the process category. In doing so, they consider force as a kind of substance that an object possesses, acquires, and consumes, rather than as an interaction between objects. In this research, learners are assumed to become metaconceptually aware of their ontological presuppositions when they explicitly reflect on their ontological beliefs about how and in what form entities exist in the world, or the properties that entities may possess as a result of belonging to an ontologically distinct category.

Throughout the instructional interventions, students provided extensive evidence of their ability to make reference to their ontological presuppositions about force concept. In Table 4.8, examples of students’ metaconceptual awareness of their ontological presuppositions about the force concept are provided. Segments related to students’ awareness of ontological presuppositions about force are italicized.
Example 1
David: I hold my ideas because of what I know about forces. They go in the direction they're exerted in. Therefore, the forces must move (through acceleration/declaration) the object in that direction. So my trouble comes in trying to figure out how a force in one direction produces movement in another. (Journal entry written in response to journal prompt 10).

Example 2
Tim: Yeah. Things that can or cannot exert force?
Kelsey: People. People can. Wait, is this can or cannot?
Tim: Can. People. Or things with energy pretty much.
Kelsey: Yeah. So cannot would be like a chair or what?
Tim: Yeah, I guess. Inanimate objects. (Excerpt from poster drawing activity, activity 1)

Example 3
David: Now I have learned about normal force, I see it as a reactionary force more than something being exerted, but for the reasons above, I definitely believe that it exists. (Journal entry written in response to journal prompt 7)

Example 4
Lisa: Inertia is a property, tendency to maintain its current motion. Force: interaction and ability to accelerate. ... Inertia is not a force. In the force diagram only gravity should be shown. (Excerpt from journal entry written in response to journal prompt 8)

Example 5
Kelsey: There is no force from your hand anymore because force is not transferred. Once you let it go the only force is friction (Excerpt from post-interview)

Example 6
David: If you know ball is sliding across the ground and hits another ball it is going to exert a force on the second ball. And the second ball is gonna move. That is energy. I think that is what they were talking about. In this situation the energy is transferred from one ball to another. But the force is not transferred. (Excerpt from post-interview)

Table 4.8: Exemplary excerpts for first-order metaconceptual awareness of ontological presuppositions.
David’s journal entry provided as the first example was written in response to an activity related to Newton’s Third Law. In his journal entry, David made reference to his ontological presupposition about force. He held the belief that forces acted in the direction they are exerted in and produce motion in that direction. Having this ontological presupposition about force and no knowledge about reaction forces, David had difficulty in understanding why exerting a force in a direction produced motion in the opposite direction. In the second example, Kelsey and Tim revealed their ontological presupposition about force when they explicitly considered force as an entity being only exerted by animate objects or objects with energy. For them, inanimate objects could not exert force.

Students participating in this study not only revealed their ontological presupposition for a single conceptual entity, but they also made ontological distinction between conceptual entities. For example, in example 3, David differentiated normal force from force being exerted by an agent. He considered normal force as a reactionary force that is different from forces exerted by an agent. In example 4, Lisa was able to make an ontological distinction between inertia and force. While she defined inertia as a property of objects, she considered force as an interaction. Her ability to make a distinction between inertia and force is clearly seen when she explicitly stated that inertia was not a force and in the force diagram it should not be shown.

In example 4 and 5, Kelsey and David revealed their ontological presuppositions about force. Having the idea that objects acquired force after they were set in motion before, Kelsey currently realized that force could not be transferred from the agent to the object. In example 6, similar to Kelsey, David also made explicit his ontological
presupposition that force was not transferred from one object to another. He displayed
evidence for his ability to compare the ontological characteristics of energy and force.
While he considered energy as an entity that could be transferred from one object to
another, for him, force did not possess the same property.

According to Vosniadou (1994), change in learners’ conceptual structure may not
only involve a change in their ideas, but also a revision in their ontological and
epistemological presuppositions that constrain their ideas. For her, conceptual change is
especially difficult when their ontological presuppositions that constrain their ideas are
entrenched and repeatedly confirmed with daily experiences. Vosniadou and Ioannides
(1998) argued that students are usually not aware of their ontological presuppositions.
They maintained that lack of metaconceptual awareness of their presuppositions causes
them to assimilate new information into a conceptual structure constrained by
inappropriate presuppositions. Therefore, awareness of one’s presuppositions plays a
critical role in developing scientifically accepted ideas.

It is clear that one’s engagement in first-order awareness of his or her ontological
presuppositions is as critical as one’s engagement in second-order awareness of
ontological presuppositions to monitor the ontological shifts in their ideas. In order to be
able to monitor the ontological changes in one’s ideas, the learner should be aware of
their past and current ontological presuppositions about a conceptual entity.

First-Order Metaconceptual Awareness of What You Do Not Know. As learners
create mental representations to explain a physical phenomenon, they may realize what
they do not know. In this study students displayed evidence for their ability to engage in
different forms of this metaconceptual process. For example, they recognized that they do not know the definition of a conceptual entity and, more sophisticatedly, they realized that they do not know whether two conceptual entities share the same conceptual definition or not. As they provided explanations for a situation, they also noticed that they do not know how a conceptual entity works in a given situation. Examples of students’ first-order metaconceptual awareness of what they do not know are provided in Table 4.9.

In example 1, Lisa realized that she did not have enough knowledge to support her ideas. Her awareness of lack of enough knowledge caused her to pay more attention to the content of their discussion. David believed that an object moving on a frictionless surface had momentum. Lisa and David realized that they did not know whether momentum was considered as a force. In doing so, they became aware that they did not know whether momentum and force share the same conceptual characteristics. They also recognized that they did not know the definition of force. In example 2, David recognized that he did not know what friction was. Although he did not know what friction was, he realized that it had to be different from his earlier understanding of friction. In example 3, David and Lisa noticed that they did not know how friction plays a role in a situation where a person on a skateboard pushed a wall.

Learners’ recognition of what they do not know potentially make them be alert to what they need to learn when they are introduced to that particular conceptual entity. In a class discussion about learning, David displayed evidence that his realization of what he did not know led him pay more attention to that conceptual entity. The excerpt taken from class discussion about learning is below.
Example 1  Lisa:  Yeah, the friction is overcoming the force from your hand more and more. But I did see the point of lack of force. That makes sense too. It's really not intelligent if you don't have enough information. I'm really interested in that conversation. It's hard. We can't really back it up.

David:  Yeah, Because we haven't done any kind of I mean ... Well, I've been trying to think of an example, but if a hockey puck, if it's just running across the rink, whether or not it has any hand pushing it across the rink, it keeps going. Yeah, if it runs into a marble, it's still gonna push the marble, but if it runs into the wall of the rink, it's not going to do anything. But it still has that momentum.

Lisa:  Yeah, is momentum a force?

David:  I don't know, but it's what we've been debating.

Lisa:  Yeah, what's the definition of force?

David:  Yeah, we don't even know what the definition of force is, so we can't really say whether the momentum is a force or not (Excerpt from group debate, activity 3)

Example 2  David:  About friction? It is just purely based on what he [the teacher] was talking about yesterday that gravity is acting down, the normal force is acting up. As far as what makes up friction, I mean those two wouldn't affect horizontal motion or straight up and down. As far as what makes friction though, I don't know so much. I'm not sure what friction is anymore. I don't know. Well, I don't think it's what I thought earlier. (Excerpt from group discussion, activity 6)

Example 3  Lisa:  I don't see how friction factors in.

David:  How does the friction factor in?

Brandon:  Okay, he pushes against the wall and if I'm pushing against the wall we are not going anywhere. I'm pushing against me and I'm pushing against it at the same speed and I have friction and it has friction. If I have wheels I have less friction and I push on it with the same force it will push me back because there's no friction holding me there. (Excerpt from group discussion, activity 10)

Table 4.9: Exemplary excerpts for first-order metaconceptual awareness of what you do not know.
Teacher: … So the whole body of science is kind of evolved because as the more we know the more we find about as we need to know. Do you see [inaudible] in terms of your study of forces or no?

David: That [discussing initial ideas] kind of helped as far as understanding what we didn’t know. Because it kind a taught what we had to pay attention to. Like initially I didn’t know what friction was, I didn’t know why something stopped or why something change direction. So you learn to pay attention to that when you actually learn why it happens as opposed to just seeing as it happens.

Teacher: So it raised your awareness of what you needed to look for?

David: Well yeah something like that. You just see everything as a part of a big picture. When you see what you don’t know you pay attention to it.

Teacher: So this is a piece of puzzle you are trying to put together or?

David: Yeah, something like that. (Excerpt taken from a class discussion)

The excerpt above shows that David saw conceptual entities as part of a big picture and his realization of what he did not know encouraged him to pay attention to the conceptual entities which were missing in the picture. His comments below also show how one’s engagement in first-order metaconceptual awareness of what she or he does not know plays a role in his or her subsequent learning of concepts. For him, his awareness that he did not know a conceptual entity made him try to figure out that conceptual entity.

David: Maybe even discussions with other students, you know, thinking about the ideas all the time and one of the things the journals and the discussions more so the journals, you are thinking about what you know and what you didn’t know, why things work. That is one of the things you have to figure out when you are writing. So as time went on I started to think about things we didn’t learn. You know, they just start try to wondering into your mind. Because your mind is open to that. It had gone into that direction. So everyone’s learning would go in that direction again because it was opened up to that it was used to that. You know, sometimes something would just click. You know why something works because your mind is again in that mood of trying to figure out what is things work and how to apply them.
First-order Metaconceptual Awareness of Contextual Differences. In this study, learners are assumed to become aware of the contextual differences when they explicitly make reference to contextual variables. In this research, context is defined as factors that involve either variables about the characteristics of the environment (frictionless surface vs. surface with friction), characteristics of objects (light objects vs. heavy objects), or situated variables (object moving as a result of being push by an animate object vs. object moving in the absence of being pushed or pulled by an animate object; object moving at a constant speed vs. object moving at an increasing or decreasing speed). Table 4.10 lists examples of first-order awareness of metaconceptual awareness of contextual differences. Segments that point out students’ first order metaconceptual awareness of contextual differences are italicized.

In example 1, David was able to compare the motion of an object on a frictionless surface and on a surface with friction. He became aware that objects on a frictionless surface kept moving, while objects moving on a surface with friction slowed down. In this example, David became aware of the differences in an object’s motion in different environments. In example 2, Kelsey realized that in everyday situation objects tended towards rest, however, in situations where there were no opposite forces objects keep moving.

Physics laws are general principles that apply to almost all contexts. On the other hand, in the case of students’ alternative ideas, although one idea seems to be working in one context, the same idea may not work in another context. Learners’ awareness of their
Example 1

David: After your hand leaves the object. It's still moving. Friction slows it down. If there were friction the object would slow down. If there is no friction there is nothing to slow it down. It wouldn't have to counteract any kind of force. It's like a hockey puck it just moves in a direction. It doesn't counter anything.

Lisa: You're saying that after the push there is no force acting upon it.

David: There's this momentum, but if it was on a certain friction it wouldn't move. It would slow down because of friction. It almost keeps going because of the lack of friction. (Excerpt from group discussion, activity 2)

Example 2

Kelsey: I thought objects tended towards rest because most objects are at rest, though I also thought it would change if acted upon by another force. In space objects do not tend toward rest because there is no opposite force. They tend to remain in their current state. (Excerpt from journal entry written in response to journal prompt 4)

Table 4.10: Exemplary excerpts for first-order metaconceptual awareness of what you do not know.

Use of ideas in different situation is critical for noticing the limitations of their ideas and for their realization that their ideas do not work in all situations. Therefore, awareness of contextual variables becomes particularly important in facilitating students’ recognition that their ideas are not generalizable to all situations. In the excerpt below, David displayed evidence for his realization that his initial ideas did not work in all situations.

Nejla: What is the advantage of learning scientific explanation over using your own idea to explain things?

David: A lot of times your own ideas don’t work all the time. They may work in the initial situations you are given because that is what you are trying to
figure out. You develop an idea and it may work for the given situation. When you go and try to figure out another situation with your initial idea it doesn’t always work. (Excerpt from post-instructional interview)

During the instructional interventions, David recognized that although his initial ideas might explain a situation, they might not work in another situation. After the instructional interventions, David displayed evidence for his acquisition of the scientifically accepted understanding of force and motion concepts. Having the ability to become aware of his use of ideas in different contexts, David realized that the ideas he held after the instructional interventions worked in more situations compared to his initial ideas.

Nejla: What about your ideas about forces? Are there any changes? You said your ideas are more sophisticated. What do you mean by that?
David: Again they work in more situations. I understand more how things work and why they work. So it is not speculative at all. I’m not guessing how it works. (Excerpt from post-instructional interview)

Students’ comments in this study indicate that having the ability to become aware of the contextual differences plays an important role in developing ideas that are generalizable to different contexts. For example, for Lisa, one way to choose one idea over another idea is to check whether the idea applies to different contexts.

Nejla: Suppose that you encounter two different ideas about the things happening in the real world. For example, a friend of yours in the class thinks that there cannot be a force without motion. Another friend of yours has a different idea. He believes that forces may act on an object that is not moving. How do you decide that one idea can explain the situation better than the other one?
Lisa: I’d probably it apply to different situations. For example, when you push the ball there is motion but when push a wall it doesn’t move. If you apply it to different situations you can see which concept applies to all the situations. (Excerpt from post-instructional interview)

The excerpt above shows that, applicability of ideas to different contexts was a criterion for Lisa to evaluate ideas. Lisa considered the idea that force might also act on non-
moving objects as a better idea because she became aware of a context in which the other idea did not work.

**First-Order Metaconceptual Awareness of Experiences.** One significant source of students’ alternative ideas about the physical phenomenon is their observation of the physical world and their superficial interpretations of their experiences (diSessa, 1993; Vosniadou & Ioannides, 1998). Therefore, it is important to reflect on experiences to increase the likelihood of learners’ recognition of their reasons for their ideas and their misinterpretations of their experiences. Students who could verbally express their past experiences and observation about the physical are assumed to be metaconceptually aware of experiences. Students in this study became aware of their experiences by making reference either to experiences in their real life or to their observations in a classroom setting. In Table 4.11, two examples of students’ awareness of their experiences are presented.

In example 1, in order to defend his idea that objects keep moving on a frictionless surface, David made reference to his experiences with hockey pucks. It is clear that his interpretation of his experience with hockey pucks was parallel with the scientific notion of inertia. In example 2, students revealed what they experienced when they pushed an object to start its motion and when they tried to keep the object moving at a constant speed. They were aware that they had to apply a bigger force to start an object’s motion compared to the force needed to keep the object moving at a constant
Example 1  David: Yeah, because we haven't done any kind of I mean... Well, I've been trying to think of an example. But if a hockey puck, if it's just running across the rink, whether or not it has any hand pushing it across the rink, it keeps going. Yeah, if it runs into a marble, it's still gonna push the marble, but if it runs into the wall of the rink, it's not going to do anything. But it still has that momentum. (Excerpt from group discussion prompted by activity 3)

Example 2  Brandon: Explain briefly what you experienced when you try to push the object at first?
Lisa: Resistance.
David: It was harder at first; it was harder to get it moving than it was to keep it moving.
Brandon: Yes, it was. Just because the way it was... Then I pushed it really lightly and it took a little bit and then it jumped to the ...
David: It did that to me too. It makes sense. It requires a larger force to get it to accelerate. All you have to do is keep it at an equal force to get it to a constant speed. Now that we know all about Newtonian physics. (Excerpt from group discussion prompted by activity 6)

Table 4.11: Exemplary excerpts for first-order metaconceptual awareness of experiences.

speed. It is worth noting that their interpretation of their experience was scientifically insufficient due to their lack of knowledge about the difference between kinetic and static friction coefficients. They only associated the difference in the amount of forces needed to start an object’s motion and to keep it moving at a constant speed to balanced and unbalanced forces, although it is also related to the difference between kinetic and static friction coefficients. The excerpt provided in the second example show that students do not always interpret their experiences in the way the scientists do.
Second-Order Metaconceptual Awareness

First-order metaconceptual awareness involves one’s explicit reference to an existing knowledge or one’s recognition of generative mental representations about a physical phenomenon. At the time learners make their ideas and elements of their conceptual ecology explicit they may monitor what they know or what they do not know. This monitoring process provides learners with information about the conceptual structure they had in the past. This information becomes available for learners when necessary. Second-order metaconceptual awareness refers to one’s reflection on knowledge that is derived from one’s monitoring of first-order metaconceptual awareness of his or her conceptual structure. It is obvious that first-order metaconceptual awareness is a minimal requirement for second-order metaconceptual awareness. The same subcategories of first-order metaconceptual awareness apply to second-order metaconceptual awareness.

Second-Order Metaconceptual Awareness of Initial Ideas/ Mental Models.

Learners engage in second-order metaconceptual awareness of initial ideas or mental models when they make reference to the ideas that they held in the past. Information about one’s past ideas is generated from learners’ monitoring of their ideas at the time they make their ideas explicit. Although being aware of a past idea implies that the learner has changed his or her initial idea with another concept, the data show that learners may make reference to an idea that he or she formed at an earlier time without having changed the past idea.
In Table 4.12, three examples of students’ engagement in second order metaconceptual awareness of their initial ideas are provided. Segments related to second-order awareness of initial ideas are italicized. In example 1, David displayed evidence for his awareness of his previous idea that there had to be an upward force in the direction of objects motion. He also recognized that he previously considered inertia as a force. The excerpt provided in example 2 serves as an example of learners’ engagement in second-order metaconceptual awareness of their initial ideas without having had a revision in their ideas. Although Kelsey still could not differentiate gravitational force and gravitational acceleration at the time she made this journal entry, she was aware that she was referring to gravitational acceleration when she used the word “gravity.” In example 3, Kelsey displayed evidence for her awareness of not only the alternative that she chose but also her idea that led her to make that choice. She was able to make reference to her initial idea that gravitational force acting on a book that was at rest on a table had to be stronger than the upward force.

It is obvious that second-order awareness of initial ideas is a process that is crucial for one’s engagement in metaconceptual monitoring of the changes in ideas. Specifically, in order to monitor the change in their ideas, learners must compare their current ideas with their previous ideas. In order to engage in second-order metaconceptual awareness of an initial idea, however, one must make that idea explicit at an earlier time.
Table 4.12: Exemplary excerpts for second-order metaconceptual awareness of initial ideas/mental models.

*Second-Order Metaconceptual Awareness of What You Did Not Know.* As learners make their ideas and elements of their conceptual ecology explicit, they acquire information not only about their former ideas, but also about what they did not know in the past. In this study, students are assumed to engage in second-order metaconceptual awareness of what they did not know when they recognize what conceptual entities they did not know in the past and what conceptual variables were missing in their initial explanations of a physical phenomenon. Examples of students’ engagement in second-order metaconceptual awareness of what they did not know are presented in Table 4.13.
Table 4.13: Exemplary excerpts for second-order metaconceptual awareness of what you did not know.

In situations provided in the activities related to Newton’s Third Law, Lisa was not able to identify reaction forces. In example 1, Lisa displayed evidence of her awareness that she did not know about reaction force (“opposite force”) before. In example 2, David recognized that he initially did not know the difference between gravitational acceleration and gravitational force. He realized that he did not know what he was referring to when he used the term “gravity.” In the third example, Lisa was aware that she did not take friction into account when she predicted the results of a demonstration involving a person on a skateboard pushing a wall.
It is clear that in order to engage in second-order metaconceptual awareness of what you did not know, learners have to become aware of the conceptual gaps in their previous conceptual structure. Therefore, one’s explicit awareness of past ideas is crucial for his or her engagement in this process.

Second-Order Metaconceptual Awareness of Contextual Differences. Learners are assumed to engage in second-order metaconceptual awareness of contextual differences when they reveal their former use of concepts in different contexts. In this research evidence was found for students’ ability to not only think about their use of concepts in different situations but also to reflect on the consistency of their use of concept in different contexts. In Table 4.14, examples of students’ ability to recognize their use of past ideas in different contexts are provided. Segments related to second-order awareness of contextual differences are italicized.

In example 1, David revealed his use of his initial idea of residual force in two situations where objects were moving horizontally and vertically. In the case of vertical motion, he initially believed that the residual force (force acquired by an object after being set in motion) was reduced by gravity. In the case of horizontal motion, he previously thought that the residual force was reduced by friction. It is clear that the contexts that he was aware of shared the same contextual variable (force in the opposite direction). The journal excerpt provided in example 2 shows Lisa’s ability to compare her initial ideas about forces across two main contexts: objects moving at a constant speed and objects moving at an increasing speed. In both contexts, Lisa believed that
Example 1  David:  … I also believed in residual forces, which is now inertia. Therefore, my ideas came from friction having to overcome this residual motion. *When in the air, I pictured this force [residual force] being reduced by gravity and when on a surface with friction I pictured it being reduced by friction.* So my ideas took gravity or friction having to spend part of its force overcoming this residual force. (Journal entry written in response to journal prompt 11)

Example 2  Lisa:  … *Another division is constant or increasing velocity.* Before I treated them the same but now I know the difference, i.e., balanced forces or no forces cause constant velocity and unbalanced forces cause acceleration or deceleration. (Excerpt from journal entry written in response to journal prompt 11)

Table 4.14: Exemplary excerpts for second-order metaconceptual awareness of contextual differences.

unbalanced forces were necessary to keep the object moving. Lisa displayed evidence for her ability to become aware of the consistency of her use of her initial idea in these two contexts when she stated that she treated them the same. Unlike David, Lisa compared her initial idea across two contexts that were different in terms of the motion of objects and the amount of forces required to move the objects. Checking the consistency of her idea in such distinct contexts allowed Lisa to notice that she incorrectly held the same idea for both contexts.

Similar to first-order awareness of contextual differences, one’s awareness of his/her use of ideas in different contexts is important in terms of detecting the inconsistencies in one’s ideas. However, the nature of the contexts that are compared by the learner may make a difference in detecting inconsistencies in one’s use of ideas. In
the first example, David compared his use of his idea in two situations that shared the same conceptual variable. In both contexts (surface with friction vs. in the air), there is opposite force acting on the objects. In the second example, however, Lisa compared two situations (objects moving at a constant speed vs. objects moving at increasing speed) that are different in terms of the comparable amount of forces acting on them.

The examples above indicate that in order to become aware of their use of initial ideas in different contexts, learners must be aware of not only their past ideas, but also the context in which the idea is used. For example, in order for David to make reference to his initial ideas across different contexts, he had to become aware his use of his idea of residual force in the contexts of motion in the air and on a surface with friction.

*Second-Order Metaconceptual Awareness of Ontological Presuppositions.* Learners are assumed to engage in second-order metaconceptual awareness of ontological presumptions when they refer to their past presuppositions about how and in what from entities exist in the world and the properties they posses by belonging to a ontologically distinct category. Two examples that display students’ ability to make reference to their past ontological presupposition are presented in Table 4.15. Segments related to past ontological presuppositions are italicized.

In the first example, as Kelsey reflected on the plausibility of the idea that inanimate objects could exert force she displayed evidence for her ability to make reference to her previous ontological presupposition. She previously believed that inanimate objects could
Example 1
Kelsey: I knew what a force was and *it wasn’t believable that an inanimate object could exert a force.* It now fits with my other ideas. (Excerpt from journal entry written in response to journal prompt 7)

Example 2
Kelsey: I thought that force would be like energy and *it can be just transferred.* Now I realize that you can’t. (Excerpt from post-instructional interview)

Table 4.15: Exemplary excerpts for second-order metaconceptual awareness of ontological presuppositions.

not exert force. In the second example, Kelsey recognized her ontological presupposition about force. She was aware that she initially considered force as an entity that can be transferred. It is obvious that in both examples Kelsey was able to monitor the ontological changes in her ideas. Having the ability to make reference to past ontological presuppositions is crucial for learners’ engagement in monitoring ontological shift in their ideas.

*Second-Order Metaconceptual Awareness of Experiences.* Although no evidence in the data was found regarding students’ engagement in second-order metaconceptual awareness of experiences, it is theoretically possible for learners to use this process. Learners who display ability to think about how they interpreted their experiences in the past engage in this process. For example, a learner may be aware of her or his former interpretation of an experience if she or he says “In the past when I saw that the heavy and light balls hit the ground at the same time I thought that the same amount of gravitational force is exerted on both balls.”

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Metaconceptual Monitoring

Metaconceptual monitoring processes refer to “online” “in the moment” processes that generate information about an ongoing cognitive activity, thinking process, or present cognitive state. While metaconceptual awareness involves one’s reflection on his or her own existing ideas and elements of conceptual ecology, learners engage in metaconceptual monitoring when they encounter a new conception or information coming from other sources. Learners are assumed to engage in metaconceptual monitoring when they monitor other people’s ideas, the comprehension of conceptions, the consistency between existing ideas and new information/experiences, and the change in their ideas. A detailed description of each type of metaconceptual monitoring processes is provided below.

Monitoring of One’s Understanding of an Idea. According to the Conceptual Change Model, one of the conditions of the change process is intelligibility of the new concept (Posner et al., 1982). In other words, in order to change their existing concept with the new one, learners must first understand the new concept. Monitoring one’s understanding of an idea becomes important in satisfying this condition. In this research, learners are assumed to engage in monitoring understanding of an idea when they explicitly state that they understand or fail to understand a new idea. Examples that depict students’ ability to monitor their understanding of an idea are presented in Table 4.16.

In example 1, 2, and 3, David, Kelsey, and Lisa claimed that they understood Newton’s First Law of Inertia. There were variations in the ways they checked their understanding of the law. While being able to use Newton’s First Law in answering
Example 1  David: I understand Newton's First Law. I know this because I comprehend that an object without something to make it move will remain stationary but if something makes it move (or stop) it will respond to that. (Excerpt from journal entry written in response to journal prompt 4)

Example 2  Kelsey: I understand the law [Newton’s First Law] and I know I do because I can use it to answer questions. (Excerpt from journal entry written in response to journal prompt 4)

Example 3  Lisa: Yes I understand that objects in motion remain in motion. I know this because I can use examples to support my thoughts. (Excerpt from journal entry written in response to journal prompt 4)

Example 4  Kelsey: Yes I understand it [why everything fall to the Earth at the same rate] and I know I do because I can mathematically solve it. I could also help or explain it to someone else. I don’t totally understand the difference between gravitational acceleration and gravitational force. (Excerpt from journal entry written in response to journal prompt 6)

Example 5  David: I'm still a little unclear why everything falls to Earth at the same rate. If the object's mass changes, won't the forces of gravity increase? But again F=m.a, so it does have to increase. If g=GM_{obj}/r^2, then obviously g will increase. Well this deserves further thought. (Excerpt from journal entry written in response to journal prompt 6)

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<th>Table 4.16: Exemplary excerpts for monitoring one’s understanding of an idea.</th>
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<td>questions was a way for Kelsey to control her understanding of the law, Lisa used examples to check whether she understood the law. In the first example, David restated the law in his own words to show that he understood the law. It is worth noting, however, that David’s understanding of the First Law only involved objects’ tendency to remain stationary. For him, objects had a tendency to remain stationary unless acted upon by a force. He did not take objects’ tendency to remain in motion into account in his</td>
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understanding of the law. Although he claimed that he understood Newton’s First Law, his understanding was scientifically unacceptable. This indicates that learners’ engagement in motoring understanding of an idea in the form of restating the idea in their own words does not guarantee that they have a correct understanding of that idea. In example 4, Kelsey displayed another way to check her monitoring of her understanding of an idea. Being able to mathematically prove it and explaining it to someone else were ways for her to make sure that she understood why objects fall to Earth at the same rate. To sum up, restating the idea in their own words, explaining it to someone else, using the idea in answering questions, providing examples in which the idea is used, and providing a mathematical proof (if applicable) were ways for students to check their understanding of a new idea.

Learners who monitor their comprehension of a new concept are more likely to detect their failure in understanding of it. In example 5, David displayed evidence for his realization of his failure to understand why objects fall to Earth at the same rate. It is worth noting that the journal entry provided in example 5 was written after seeing a demonstration that showed that heavy and light objects fall at the same rate. David knew that the gravitational force acting on an object increased as the mass of the object increased. Having the idea that objects being acted by a greater gravitational force fall faster, he could not understand why heavier object did not fall faster. Having not understood the situation, David displayed evidence that he had an intention to pay effort to rethink about the situation (“Well this deserves further thought.”). His comments indicate that learners’ recognition of their failure to understand a concept enhances the
likelihood of their dissatisfaction with their current state of cognitive functioning and consequently their tendency to pay effort to understand the new information.

*Monitoring Ideas/Information of Other People/Source.* In order to change one’s existing ideas with new ones, a learner should first recognize the new information. In this study, students displayed evidence of not only becoming aware of their own ideas, but also recognizing other people’s ideas. One’s realization of other people’s ideas is a minimal requirement for noticing the consistency between her or his own ideas and the new idea belonging to other people. Examples of students’ engagement in monitoring other people’s ideas are presented in Table 4.17.

<table>
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<tr>
<th>Example 1</th>
<th>David: One member of the group said B would be correct, because the 3 arrows were gravity and the big arrow was the force of the book on the table. Later on, after further consideration, she remarked that if that were true the book without resistance would accelerate through the table. (Excerpt from journal entry written in response to journal prompt 7)</th>
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<td>Example 2</td>
<td>Lisa: He does not believe that a force is acting on it because the hand is gone. (Excerpt from journal entry written in response to journal prompt 3)</td>
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<td>Example 3</td>
<td>Kelsey: They thought that momentum was a force. (Excerpt from journal entry written in response to journal prompt 3)</td>
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Table 4.17: Exemplary excerpts for monitoring ideas of other people.
In example 1, David displayed evidence of his ability to monitor one of his group member’s choice of the alternatives that depicted the forces acting on a book that is at rest on a table. He was able to monitor that his friend chose alternative B, which showed one big and three small downward arrows. David was also able to recognize his friend’s realization that the book would accelerate if her choice were correct. In example 2, Lisa monitored her group member’s belief that no force from the agent acted on the object after the object lost contact with the object. In example 3, Kelsey was able to recognize that her friends considered momentum as a force. In all examples, students did not compare other students’ ideas with their own ideas but, rather, they only make reference to the content of other students’ ideas.

Monitoring the Consistency Between New Idea and Existing Idea. The data collected show that learners’ abilities were not limited to only monitoring the new information coming from various sources but learners are also capable of checking the consistency between what they already believe and the new ideas. In doing so, learners make reference to their existing ideas and compare those with information coming from other sources. It is clear that learners’ recognition that there is another idea that is different from their own ideas is a key process for considering a change in ideas. In Table 4.18, examples of students’ engagement in this process are provided. Segments related to monitoring consistency between a new idea and an existing idea are italicized.
Example 1  David: Some said weight and smoothness/roughness of table were forces, *but I think they are not forces but only manifestations of gravity and friction.* (Excerpt from journal entry written in response to journal prompt 2)

Example 2  David: It was proposed that the force from the hand is gone when the hand leaves the book; the motion of the book is caused by residual force. Good. *I'm not the only one who thinks that.* We debated whether the residual motion of the book was a force. (Excerpt from journal entry written in response to journal prompt 2)

Example 3  Kelsey: *My current ideas are consistent with Newton’s Laws.* (Excerpt from journal entry written in response to journal prompt 11)

Example 4  Kelsey: *They thought that momentum was a force and I didn't which was the main disagreement.* (Excerpt from journal entry written in response to journal prompt 3)

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<th>Table 4.18: Exemplary excerpts for monitoring the consistency between a new idea and an existing idea.</th>
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<td>In example 1, David displayed evidence of his ability to monitor that some students considered weight and smoothness/roughness of the table as forces. He engaged in monitoring consistency between his own idea and ideas of other students when he indicated that he disagreed with other students’ ideas. He explicitly stated that he did not consider these variables as forces but he believed that they were only manifestations of gravity and friction. In example 2, David was able to monitor that other students and he had the same belief about the force needed to keep an object moving after it lost contact with the agent. Similarly, in example 3, Kelsey was able to monitor the consistency of her ideas about force with Newton’s Laws. She claimed that her current ideas were in</td>
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agreement with Newton’s Laws. In example 4, Kelsey recognized that the students in her
group considered momentum as a force. She was able to monitor that this idea was not
consistent with what she believed.

The excerpts in Table 4.18 show that learners must become aware of their existing
ideas and recognize information coming from various sources in order to engage in
monitoring consistency between existing ideas and new ideas. In other words, first-order
metaconceptual awareness of one’s ideas and monitoring information of other
people/sources are prerequisites for one’s engagement in this comparative monitoring
process.

Monitoring the Consistency between Existing Idea and New Experience. Similar
to learners’ ability to compare existing ideas with other people’s ideas, they are also
capable of comparing their own ideas with what they observe and experience. For
example, learners who compare their predictions for a given situation with the result of
an experiment or demonstration are assumed to engage in this metaconceptual processes
According to the Conceptual Change Model (Posner et al., 1982), cognitive conflict
between existing beliefs and new information must be experienced before conceptual
change can take place. One’s realization that there are differences between what they
believe and what they observe or experience (anomalous data) promotes the likelihood of
having cognitive conflict and consequently dissatisfaction with current conceptual
structure (Limon, 2001). In Table 4.19, examples of students’ engagement in
metaconceptual monitoring of the consistency between their ideas and experiences are
provided.
Example 1  David: *All my predictions were off*. I figured that equal forces [action and reaction forces] would cancel each other out not produce movement anyway. (Excerpt from journal entry written in response to journal prompt 10)

Example 2  Kelsey: *What we observed didn’t support some of my individual ideas.* All of the demos involved mass and force and movement. …The student D traveled farther then the others because there was a smaller mass. The student on the skateboard couldn’t push the cart forward and was pushed back because there was little friction with the ground. (Excerpt from journal entry written in response activity 10)

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<th>Table 4.19: Exemplary excerpts for monitoring the consistency between existing ideas and new experience</th>
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In example 1, David displayed evidence of his engagement in monitoring the consistency between his existing idea and his observations when he explicitly stated that his initial predictions for the given situations (see Activity 10 in Appendix C) were different from what he observed. In doing so, he made reference to his initial thought that action and reaction forces would cancel each other out and no movement would be observed. In a similar way, in example 2, Kelsey was able to monitor that her ideas were different from what she observed during the demonstrations performed as part of activity 10. Kelsey displayed also evidence for her ability to monitor what she observed as she explained the results of the demonstrations.

The excerpts presented in Table 4.19 show that learners must make reference to their initial ideas/predictions and monitor the information generated from an experience/observation in order to engage in this metaconceptual process. Therefore,
second-order metaconceptual awareness of initial ideas and monitoring information
coming from various sources are embedded within this process.

Monitoring Change in Ideas. Monitoring the change in one’s ideas is a process in
which learners make a comparison between what they initially knew and what their
current ideas are. It is obvious that second order awareness of initial ideas and first-order
awareness of current ideas is a minimal requirement for making this comparison. The
data collected in this study showed that students may not only recognize their initial
ideas, but they may also reveal what they did not know initially as they make reference to
the changes in their ideas. Examples that depict students’ ability to monitor changes in
their ideas are presented in Table 4.20.

David’s journal entry presented in example 1 points out his ability to monitor the
change in his idea regarding gravity overpowering the horizontal inertia of a bullet shot
horizontally. He explicitly revealed that his current idea was different from what he
believed initially. As opposed to thinking that gravity overpowered horizontal inertia (he
initially thought that the horizontal speed decreased due to this reason), he currently
believed that the vertical speed of the ball became relatively high compared to the
object’s constant horizontal speed. In the excerpt taken from group discussion about
forces acting on a book that was at rest on a table, Kelsey made reference to the change in
her choice of the alternatives that depicted forces acting on the book. She was able to
monitor that she initially chose alternative E (bigger force in the downward direction and
smaller force in the upward direction), and later she changed her answer to D (equal
forces in the upward and downward directions). In example 3, Lisa displayed
Example 1  David: After further discussion, I have changed my idea on gravity overpowering the horizontal inertia. As opposed to thinking that the power of gravity negates the inertia (like a bulldozer pushing on a speeding car), I now believe differently. I think the ratio between horizontal and vertical velocities becomes such as gravitational downward acceleration increases downward bullet’s speed so that (1:2; 1:3; 1:4) the slope appears to almost turn downward. (Excerpt from journal entry written in response to journal prompt 9)

Example 2  Brandon: I thought it was D. The reason why I thought it was D is because the book is not accelerating which means that the forces are balanced and D is the only one with the forces being balanced.  
Kelsey: I actually went with E but when I thought about it later I actually switched to D because I thought they were balanced. (Excerpt from group debate prompted by activity 5).

Example 3  Lisa: The words I used to express my ideas were defined differently than how I used them…. What I thought of as included in my definition of force, Newton called inertia…. My [current] definition includes:  
Inertia: a constant velocity  
Force: an acceleration (unbalanced)  
I didn’t define what these two ideas individually did. (Excerpt from journal entry written in response to journal prompt 4)

Example 4  Kelsey: I realized that my initial ideas didn’t account for reaction forces being exerted…. I now see that reaction forces can actually exert their own force in a way to move something. Discussing it as a class made me change. (Excerpt from journal entry written in response to journal prompt 10)

Table 4.20: Exemplary excerpts for monitoring change in ideas.
evidence of her ability to monitor changes in her ideas as she revealed the conceptual differences between her initial definition of force and scientific view of inertia. She was aware that she initially considered inertia as a force and could not differentiate the outcome of these two conceptual entities. She realized that her initial understanding of force and Newton’s notion of inertia were different. She made reference to her current understanding of inertia and force as she differentiated the outcome of inertia and unbalanced forces. It is obvious that in example 1, 2, and 3 David, Kelsey, and Lisa made reference to their initial and current conceptual understanding. In example 4, however, Kelsey recognized that she acquired an understanding of a conceptual entity that was missing in her initial conceptual structure. She realized that she did not know about reaction forces before and she currently believed that reaction forces existed. The excerpts provided in Table 4.20 show that monitoring changes in ideas involve one’s realization of the ideas that are not only accommodated but also assimilated in one’s conceptual structure.

Monitoring the changes in ideas is a metaconceptual process that takes place as learners change their ideas. However, this process is significant in maintaining the durability of learners’ current ideas due to its capability to generate information about the validity of initial and current ideas. Students in this study displayed evidence for the coexistence of their well-formed initial and current ideas about forces and for their acquisition of knowledge about the validity of their initial and current ideas:

Nejla: What happens to your old idea after you accept a new idea? Is it still there or you just forget it?
Lisa: If I really form the initial idea as I did in inertia it is still there. But like in some other ideas, concepts, if I didn’t form the initial idea or if the initial idea is so much the same as the what the scientifically accepted one is…
Nejla: Do you still use your initial idea?
Lisa: For inertia?
Nejla: Inertia or other concepts? Whenever you are exposed with a situation where for example forces acting on objects do you still think about your initial idea of inertia sometimes?
Lisa: Yes.
Nejla: Could you describe what you think when you are asked a question about forces acting on objects, supposedly a ball is thrown up for example?
Lisa: I think about my idea of inertia. It comes to my mind still but I know that I changed it and it is accepted as wrong answer. And I give the right answer.
(Excerpt from post-interview)

In the excerpt above, Lisa maintained that her well-formed initial ideas about forces came into her mind whenever she was asked a question about forces acting on objects. For example, she remembered her initial idea of inertia (acquired force in the direction of object’s motion keeps the object moving) when she was asked forces acting on objects. When this happens, she realized she changed her initial idea of inertia. Lisa was not only aware that her current idea was different from her previous understanding of inertia, but she was also able to recognize that her initial ideas were wrong. Having information about the validity of her initial and current ideas, Lisa claimed that she used her correct idea when she was asked.

Like Lisa, Kelsey also displayed evidence that she acquired information about the validity of her initial and current ideas as a result of monitoring changes in her ideas, and she chose to use her correct idea when necessary. The excerpt taken from the interview conducted after the instructional interventions is provided below.

Nejla: What happens to your old idea after you change it with a new idea?
Kelsey: Some of them I definitely forget but some of them I kind a remember if I saw [inaudible] I remember thinking that. I guess it depends on how much we built around the idea. If we have a lot of evidence to support our idea then that was harder to block out. That is still kind of there
because if I saw it I remember it. But some of them were so way off like where did it come from I wouldn’t even remember it.

Nejla: What about forces acting on objects? Do you sometimes remember your initial ideas?

Kelsey: Sometimes I can like…. Sometimes I can automatically decide to think the real one. But sometimes I know… We talked on Tuesday about centripetal force. I remember that I used to think it is like… I always think backwards on that one. I think like okay wait what I used to think was wrong. So sometimes I do think that way.

Nejla: Do you compare scientific ideas with your initial ideas whenever you think this way?

Kelsey: I don’t know if I compare some of them. I just remember and then I think the opposite way. Like I used to think that and that was wrong while the opposite was true. (Excerpt from post-interview)

Like Lisa, Kelsey also thought about her well-formed initial ideas and current ideas at the same time when she provided explanation for a physical phenomenon. For example, she remembered that she initially believed that centripetal force acted in the outward direction. However, knowing that this idea was not true, she used a correct scientific explanation.

It is clear that learners acquire information about the validity of their previous and current ideas as they monitor changes in their ideas. This information becomes available to them when they remember their initial ideas. Having information about the incorrectness of their initial ideas, learners prefer to use their latest conceptual understanding. Therefore, restructuring in learners’ conceptual understanding would be more permanent as long as students retain knowledge about the validity of current and initial ideas that are generated from metaconceptual monitoring of the changes in ideas.

Metaconceptual Evaluation

As learners learn new conceptions that are different from what they already believe, they may evaluate competing ideas by making judgmental decisions about them.
In an attempt to describe why an idea explains the physical phenomenon better than the other idea, they may make comments about the validity of competing ideas and provide justifications for them. This process requires the learner to make comments “about” ideas. The data collected in this research show that learners engage in this evaluation process in different forms.

1. Learners make comments about the plausibility and usefulness of existing and/or new ideas. Hewson (1981) maintained that conceptual change cannot occur without concomitant changes in the relative status of competing concepts. He emphasized learners’ decisions about the plausibility and fruitfulness of competing conceptions in the process of changing their conceptions. Making judgmental decisions about the relative status of conception requires the learner to engage in a comparative evaluation process. As learners make comments about the relative plausibility and fruitfulness of ideas, they explain why an idea is attractive, believable or useful to them. However, they do not always use a terminology to talk about the plausibility of their ideas. They simply refer to the plausibility of an idea by explicitly stating that an idea is right or wrong and providing reasons or justifications for the validity of ideas.

2. Learners choose an idea among different alternatives and defend why that idea works better than the other ones for the given situation by providing justifications for their choice.

Although the ways students engage in metaconceptual evaluation differ, there are no categorical variations in the above stated forms of metaconceptual evaluation. In other words, the qualitative differences seen in the subcategories of metaconceptual awareness
and metaconceptual monitoring are not seen in the above-stated forms of metaconceptual evaluation. For example, although monitoring one’s understanding of an idea is qualitatively different from monitoring the consistency between new and existing ideas, a similar categorical variation is not seen in making comments about the plausibility of ideas and choosing an option among several alternatives, along with providing justification for one’s choice, as the aim of engaging in both forms of metaconceptual evaluation is to explain why an idea works better than another one.

Examples that depict students’ ability to engage in the first form of metaconceptual evaluation are provided in Table 4.21. Segments related to metaconceptual evaluation are italicized. In example 1, David maintained that the idea of an upward force changing in the air as the object’s position changed was not plausible to him. He recognized that his classmate’s idea was wrong because she considered inertia as a force. Having the ability to differentiate between force and inertia and having the ontological presupposition that forces did not change in the air, David did not find his classmate’s idea believable.

In example 2, Kelsey did not use a terminology to state that her group’s previous idea was no longer plausible to her. But, rather, she made comments about the validity of her group’s idea by directly stating that the idea was wrong. She maintained that their previous idea that force implied motion was wrong. Kelsey was also able to provide justification for the inaccuracy of that idea by giving an example that involved an object that did not move even though force was acting on it.

In example 3, Kelsey engaged in metaconceptual evaluation by stating that she currently found an idea, which was not believable initially, plausible because that idea
Example 1  David:  I didn't find any attractive ideas; though my idea changed during initial discussion. The only idea that struck me as truly odd was the idea that upward force would change as the ball's position changed. I think she must have been thinking of inertia as a force; otherwise it doesn't make sense. (Excerpt from journal entry written in response to journal prompt 8)

Example 2  Kelsey:  When we first thought that motion was necessary for force, we were wrong. It [force] does not always create motion. You can push on a building as hard as possible but it will not move. (Excerpt from journal entry written in response to journal prompt 2)

Example 3  Kelsey:  I understand that the table exerts an upward force…. It is different from what believed before. It wasn’t believable that an inanimate object could exert a force. It makes sense because it now fits with my other ideas and I’m able to forget my preconceptions if I learn that I’m wrong. Well I changed my answer. (Excerpt from journal entry written in response to journal prompt 7)

Example 4  Lisa:  The way Newton’s Law and the definition of words [inertia] put my views into a clearer nature. It makes my ideas look nicer, neater and is easier to work with…. If you define force as an interaction my statement is wrong. It’s all a word game. What I thought of as included in my definition of force, Newton called inertia. Newton’s definitions and laws better explain motion. It divides my definition of force into different groups based on what happens to the objects. (Excerpt from journal entry written in response to journal prompt 4)

Table 4.21: Exemplary excerpts for metaconceptual evaluation involving students’ comments about plausibility and usefulness of ideas.
was compatible with her other ideas. Although the idea that an inanimate object could exert a force was not believable to her, that idea currently made sense to her because it fit with her other ideas.

In the excerpt of a journal entry provided in example 4, Lisa displayed her ability to metaconceptually evaluate Newton’s First Law against her previous idea of acquired force (force acquired by an object after being set in motion keeps the object moving). Kelsey not only made comments about the inaccuracy of her initial idea of acquired force, but she also articulated the relative usefulness of Newton’s First Law. For her, Newton’s Laws were clearer and easier to use. She maintained that Newton’s First Law distinguished the conceptual entities (inertia and force) based on the type of motion of the objects, although her previous understanding could not differentiate constant speed and acceleration as the outcome of force and inertia.

Table 4.22 presents examples that depict students’ ability to engage in metaconceptual evaluation, which involves choosing an idea among several alternatives and providing justifications for the chosen idea. In example 1, David engaged in metaconceptual evaluation as he provided justification to explain why an idea could not explain the physical phenomenon. In an attempt to defend the alternative that depicted the forces acting on a ball tossed up, David explained why alternative B (equal upward and downward forces) could not be the correct choice for the given situation. Based on what he knew about the outcome of balanced forces, David argued that the ball would continue at a constant speed if equal amounts of upward and downward forces acted on the ball. In response to his classmate’s comments that the ball would stop if the forces acting on it
Example 1

Laura: So then it should be more like B or A? The forces have to be balanced so then wouldn't it be like this at the top? There's gravity and upward force.

David: *It if were like B, then the ball would continue upward at a constant speed.*

Laura: Or it would have stopped.

David: No.

Laura: Yeah.

David: *It would have to decelerate before it would be able to stop. In your case, the forces would have to change in mid air and they're not going to do that because gravity is constant and there's no force being exerted on the ball upwards.* (Excerpt from group debate prompted by activity 7)

Example 2

David: *This combined with what we learned in class about forces led me to believe that if choice D weren't correct, and the table weren't exerting an equal upward force, then the unbalanced forces would accelerate the book through the table.... The book isn't accelerating downward. It remains stationary. If you lifted it up, it would accelerate downward because without resistance to gravity there are unbalanced forces. This book is on the table though. The up arrow is the table's reaction to gravity.* (Excerpt from journal entry written in response to journal prompt 2)

Table 4.22: Exemplary excerpts for metaconceptual evaluation involving choosing an idea among several alternatives.

were equal, David defended his own position by making reference to his ontological presupposition that the forces did not change in the air.

In example 2, David displayed his ability to engage in a metaconceptual evaluation process that is similar to that seen in example 1. In an attempt to defend his choice among several alternatives that depict the forces acting on a book that was at rest on a table, David provided justification for his choice. Based on what he knew about the
outcome of balanced and unbalanced forces, David explained what would happen if his choice (equal amount of upward and downward forces act on the book) were not accurate. For him, among other alternatives choice D was the correct explanation for the given situation because the book was not accelerating.

*Criteria That Provide Basis for Metaconceptual Evaluation*

The data collected in this study indicate that as students engage in metaconceptual evaluation they make judgmental decisions about ideas and provide justifications for ideas based on different criteria.

*Existing Ideas and Ontological Presuppositions.* The examples provided in Tables 4.22 and Table 4.22 above (example 3 in Table 4.21, and example 1 and 2 in Table 4.22) show that one of the criteria students used to evaluate new ideas is what they already know. As seen in example 3 presented in Table 4.21, compatibility of the new idea with existing ideas caused Kelsey to find the new idea plausible (“It makes sense because it now fits with my other ideas…”). In examples 1 and 2 presented in Table 4.22, David made comments about the validity of ideas based on what he knew about the outcome of balanced and unbalanced forces. In the second example seen in Table 4.22, David also used his ontological presuppositions about force (forces do not change in the air) as he defended his ideas.

*Experimental/Experiential Evidence and Experiences.* Other than their existing ideas and ontological presuppositions, students make judgmental decisions about ideas based on experimental/experiential evidence. In the excerpt taken from a group
In activity 6, students were asked to compare and measure the amount of forces needed to start an object’s motion and to keep it moving at a constant speed. In the above excerpt, David commented on his experience that the force needed to start an object’s motion was greater than the force needed to keep it moving at constant speed. In response to Lisa’s
claim that the force to keep the object moving at a constant speed could be larger, David defended the opposite idea (force to keep the object moving at a constant speed is smaller than the force to start the object’s motion) by drawing on the experiential information generated during the hands-on experiment (“Well we haven't finished the course yet. But, I'm going on what I experienced and that was…”).

In an interview conducted after the instructional interventions, Kelsey maintained that she evaluated ideas based on what she observed during demonstrations.

Nejla: You have told me different things about how people learn science. Could you tell me in a big summary about what you know about how people learn science?
Kelsey: I think seeing is a big thing like demonstration. When I see it then I believe it. To me seeing a demonstration is a kind of proof that is what I believe. Like I didn’t believe that objects fall at the same time when they are dropped until I saw it. So that proves that I’m right or wrong and that definitely helps because then I can move on faster and it is kind of like factual evidence. So seeing demonstration definitely helps me.

In the above excerpt Kelsey explicitly stated that she considered the information generated from her observations of demonstrations as a proof to decide whether the ideas were right or wrong. For example, she did not consider the idea that object fall at the same time as plausible until she observed it in a demonstration.

Students in this study also used experiences from daily life as they made judgments about the validity of ideas. In the excerpt below taken from the post-instructional interview, Kelsey indicated that examples from daily life helped her decide which idea was right.

Nejla: Suppose that you encounter two different ideas about the things happening in the natural world. For example a friend of yours thinks that there cannot be force without motion. Another friend of yours has a different idea. He believes that forces may act on an object that is not
moving also. How do you decide that one idea can explain the situation better than the other one?

Kelsey: I guess I would just use an example or something. Like a chair. I’d say forces are acting on it obviously like gravity is acting on it. Probably that is the one she would know for sure. Because the normal force is acting up. So I guess I would just use examples to show the one who thought the wrong idea.

Nejla: If you didn’t know about the balanced and unbalanced forces would any of these ideas be attractive to you?

Kelsey: Initially I probably agree with the first one and then I think about it like we can push on the wall but it won’t move. So I guess it depends on how long I thought about it. Initially I would go with that yeah if there is force there is motion because of my experiences in everyday life like if I push something it moves but if I don’t push it, it is not gonna move anywhere. But then if I start thinking of more examples and thinking that way like if you push something really heavy like a car… You still apply force to it but there is no motion.

Nejla: So one of the things that help you to decide which one is better is the examples you think of from daily life?

Kelsey: Yeah.

In the above excerpt, Kelsey maintained that she thought of examples drawn from her daily life experience to evaluate competing ideas. For example, in order to decide which of the two ideas (there is always motion present when force acts on an object vs. objects do not necessarily move even though forces act on it) was accurate, Kelsey drew on experiences in which one of the ideas did not work. For example she drew on her experiences with heavy objects like a car that did not move even though force was exerted to push it. In doing so, Kelsey had the epistemological assumption that the incorrect explanation does not apply to all situations. This criterion, which influences students’ judgmental decisions about the validity of ideas, is described below.

Epistemological Beliefs about the Generalizability of Ideas. When students encounter new ideas, they also evaluate the relative validity of ideas based on the
generalizability of them to different situations. After the metaconceptual instructional interventions, David, Lisa, and Kelsey displayed evidence that they consider the idea that works in all situations as the correct idea. The excerpt taken from post-instructional interview is an example that shows David’s acquisition of knowledge about the generalizability of scientific ideas after the instructional interventions.

**Nejla:** When you encounter a new idea that is different than your own idea, how do you know that the new idea is better than your own idea?

**David:** I don’t know that I would answer this a couple months ago. I suppose if the new idea, the correct idea applies to more situations and it works every time and it works in the same way… Your initial ideas may work in the situations that you are trying to figure out but the proven facts work everywhere again in the same way. A lot of the time they make more sense and they will allow other ideas to become true as well.

David’s comments above indicate that he did not have knowledge about the generalizability of the scientifically accurate ideas to different situations before the instructional interventions. For him, ideas that applied to every situation in the same way were correct and made more sense. Having this epistemological assumption, David tried to think of a situation where one idea did not work to decide whether an idea was correct:

**Nejla:** Suppose that you encounter two different ideas about the things happening in the natural world. For example, a friend of yours thinks there cannot be a force without a motion. And another friend of yours has a different idea. He believes that forces may act on objects that is moving. How do you decide that one idea explains the situation better than the other one?

**David:** I try to find a situation where one idea doesn’t work. If you are trying to figure out I mean forces don’t have to cause motion. Look at the ground we are sitting on the ground we are not moving but there are forces acting us. They are preventing movement. They are canceling out movement. So that idea does not apply to this situation. It is not correct. Trying to find situations where it doesn’t work.
In the above excerpt, David explicitly indicated that an idea that did not work in a situation was not accurate. Lisa gave a similar response when I asked her the same question.

Lisa: I’d probably apply to different situations. For example, when you push a ball there is motion but when push a wall it doesn’t move. If you apply it to different situations you can see which concept applies to all the situations.

Like David, Lisa applied ideas to different situations and checked which idea applied to all situations in order to make a decision about the validity of an idea.

**Summary of the Types of Metaconceptual Processes**

In this study, evidence for three main types of metaconceptual processes was searched in the data of three students selected from the experimental group: metaconceptual awareness, metaconceptual monitoring and metaconceptual evaluation. These main types of metaconceptual processes were derived from the theoretical arguments about conceptual change process and about the qualitative distinctions in the metacognitive processes presented in the taxonomies of metacognition. In analyzing data, the data were searched to find evidence for different categories within each type of the metaconceptual processes. In doing so, I was not only responsive to theoretical claims raised in the literature about metacognition and conceptual change, but also to what emerged from the data.

Within metaconceptual awareness, evidence for two types of awareness was found in the data: first-order metaconceptual awareness and second-order metaconceptual awareness. The former involves one’s awareness of an information resulted from monitoring of the former one. While first-order metaconceptual awareness refers to
learners’ recognition of stored or dynamic representations or ideas about the physical world and elements of their conceptual ecology, second-order metaconceptual awareness involves one’s awareness of ideas and elements of conceptual ecology that they had in the past. It is obvious that one’s engagement in first-order awareness is a minimal requirement for one’s engagement in second-order metaconceptual processes. In both types of metaconceptual awareness, learners make reference to elements of their existing conceptual system rather than new information. The same subcategories were observed within each level of metaconceptual awareness. During learners’ engagement in first and second-order metaconceptual awareness, they make reference to the following elements: ideas/representations about physical world, ontological presuppositions, contextual differences, experiences, and conceptual entities that are not known. Metaconceptual monitoring involves online processes that generate information about an ongoing cognitive process or cognitive state.

Unlike metaconceptual awareness, learners encounter new information as they engage in metaconceptual monitoring processes. Evidence for the following types of monitoring processes was found in the data: monitoring understanding of an ideas, monitoring information coming from other people or sources, monitoring the consistency between existing idea and new information, monitoring existing idea, and new experience and monitoring changes in ideas. Learners’ engagement in the last three of the listed monitoring processes requires them to compare the encountered new idea or observed information with existing or past ideas. In doing so, learners engage in more sophisticated monitoring processes compared to monitoring information coming from other sources.
Metaconceptual evaluation is a process in which learners make judgmental decisions about competing ideas and provide justifications for them. The data collected from the three students show that students make comments about the plausibility and usefulness of ideas or choose one idea among several alternatives and provide justifications for the validity of the chosen idea as they evaluate ideas. Students use different criteria as they make comments about the validity of ideas. Students make judgments about the validity of an ideas based on what they already know and what assumptions they make about the ontological characteristics of entities. Their observations and experiences serve for them as factual evidence to believe in the validity of an idea. In this study, three students who were the focus of the case studies acquired knowledge about the generalizability of the scientific knowledge to all situations. For them, ideas that work in every situation were valid. As they compare one idea to another, they think of situations in which and idea does not work. Credibility of the source from which the idea comes is another factor that influences students’ decisions about the validity of ideas.

To sum up, the data presented in this Chapter involve a variety of examples that shed light into the nature and different forms of metaconceptual processes that students engaged in as they participated in the instructional activities used in the experimental group. Categorization of students’ metaconceptual thought illuminated the multidimensional nature of metaconceptual processes. Metaconceptual thought is multidimensional in the sense that various subcategories were found within each type of metaconceptual process. These processes are qualitatively different in terms of their object of the process and the information generated from them. For example, in the case
of monitoring one’s understanding of a new idea the object of the process is the new idea, and it generates information regarding one’s success or failure to comprehend a new idea. On the other hand, in the case of second-order awareness of initial ideas, the object of the process is one’s previous ideas and it generates information about one’s previous conceptual structure.

The data also revealed that some categories of metaconceptual processes are multifaceted and also interdependent. For example, monitoring consistency between existing and new ideas/experiences and monitoring changes in ideas involve one’s engagement in other types of metaconceptual processes. Specifically, in order to engage in monitoring changes in ideas, learners should compare their initial ideas with their current ideas. Therefore, as learners monitor changes in their ideas, they also engage in first-order and second-order metaconceptual awareness of ideas. In that sense, monitoring changes in ideas entails first-order and second-order metaconceptual awareness of ideas, and the latter processes are the prerequisites of the former. Second-order metaconceptual awareness is a process in which learners make reference to a knowledge that resulted from monitoring first-order level of metaconceptual awareness. Thus, first-order metaconceptual awareness is a minimal requirement for learners’ engagement in second-order metaconceptual awareness. For example, in order to make reference to an initial idea learners should make that idea explicit at a time and they should monitor that idea at the time they make reference to that idea. In Figure 4.2, a relational representation of the interdependent nature of the metaconceptual processes is presented. The direction of the arrows indicates which metaconceptual process is a prerequisite of another process.
Data analysis clearly supports the view that metaconceptual thought involves various levels of sophistication. Some types of metaconceptual processes are more sophisticated than other ones in the sense that sophisticated ones demand an action on the less sophisticated ones or require more abstract thinking. For example, monitoring the consistency between new and existing idea requires a comparison between one’s existing idea and new information coming from another source. In that case, the learner not only engages in first-order awareness of the content of his/her idea and monitoring new information coming from other people but s/he also compares the information generated
from these processes. In that sense, monitoring the consistency between existing and new idea is a more sophisticated process than first-order metaconceptual awareness of ideas and monitoring ideas of other people. Metaconceptual evaluation involves learners commenting on the status of competing ideas, noticing the limitations and implications of ideas, drawing inference about ideas, providing justifications for the validity of ideas. It is obvious that these processes require a more purposeful and abstract thinking compared to simply articulating the content of ideas about the natural world.

In this chapter, the results of the data analysis performed to answer research question presented in Chapter 1 are described. In the next chapter, the complete study is reviewed, and outcomes of the analyses reported in this chapter are summarized and discussed.
CHAPTER 5

CONCLUSIONS AND IMPLICATIONS

Introduction

The purpose of this study was multifaceted: This study investigated the effect of facilitating students’ metaconceptual processes on their conceptual understanding of force and motion and the durability of the impact of metaconceptual teaching on students’ conceptual understanding. In this study, the effectiveness of facilitating students’ metaconceptual processes and the durability of the impact of metaconceptual teaching on students’ conceptual understanding was examined in comparison to the effect of traditional instruction. This study also aimed to describe the nature of students’ metaconceptual processes in relation to their conceptual understanding.

This study was conducted in the two classrooms of a physics teacher during the first semester of the 2003-2004 academic year. Participants of this study consisted of 45 grade eleven and twelve students who were enrolled in two physics classes. A multi-method design, which incorporated experimental and case study design, was employed. An experimental design was used to compare the effect of metaconceptual teaching interventions with traditional instruction on students’ conceptual understanding assessed immediately following the instruction and nine weeks after the instructional interventions. Students in the experimental group were exposed to metaconceptual
teaching interventions while students in the control group were taught by traditional instruction. Three students from the experimental group were selected to gain insight into the nature of their metaconceptual processes in relation to the change in their conceptions of force and motion. The analyses of data collected from all students in both groups in the form of their scores on Force Concept Inventory (FCI) and from the three students in the form of journal writings, audio-recording of group-based activities and video-recording of classroom discussions were presented in Chapter 4. This Chapter contains three major sections: In the first part, conclusions from this study are summarized and the findings for each research question are discussed. The second part focuses on the implications that this study has for instruction and educational research. In the final part, suggestions for future research are provided.

Conclusions of the Study

The research questions posed in this study were:

7. What are the effects of metaconceptual teaching practices on students’ understanding of force and motion concepts?

8. What are the effects of metaconceptual teaching practices on the durability of students’ understanding of force and motion concepts?

9. What is the nature of the metaconceptual processes students engage in during the metaconceptual teaching practices in relation to their conceptual understanding of force and motion?
In this section the findings for each research question are reviewed and conclusions are discussed in the light of the theoretical arguments about conceptual change process and metacognition raised in the literature.

*Question 1: Effectiveness of Metaconceptual Teaching Practices on Students’ Conceptual Understanding Assessed Following Instructional Interventions*

In this study, the effectiveness of metaconceptual teaching practices used in the experimental group was investigated in comparison to the effect of traditional instruction on students’ conceptual understanding of force and motion. Students’ conceptual understanding was assessed by students’ scores on the FCI. Since the distracters of the FCI involve alternative ideas that students may potentially possess about force and motion, the higher scores on the FCI indicate a better conceptual understanding and a smaller number of alternative ideas. In order to control the differences between experimental and control groups in terms of students’ conceptual understanding that they had prior to the instructional interventions, analysis of covariance (ANCOVA) was used to analyze the data. In doing so, students’ pre-instructional FCI scores were used as the covariate so that the differences between the experimental and control groups in terms of their conceptual understanding could be attributed to the instructional treatments rather than to the differences in students’ conceptual understandings that existed prior to the instructional interventions.

The ANCOVA, which was generated to compare the experimental and control groups in terms of their conceptual understanding assessed by FCI administered following the instructional interventions, resulted in significant F values for pre-instructional (F=27.17, p<.05) and post-instructional FCI scores (F=11.18, p<.05). This
result indicates that there was a significant mean difference between experimental and control groups following the instructional interventions in students’ FCI scores in favor of the experimental group and the significant differences in students’ pre-instructional conceptual understanding that existed prior to the instructional interventions were statistically controlled. In other words, students in the experimental group who were exposed to metaconceptual teaching interventions significantly outperformed students in the controlled group who were taught by traditional instruction in terms of their conceptual understanding. The effect size was found to be 0.22, indicating the large effect size of the instructional treatments. It implies that the significant mean difference was not due to high number of participants, but due to the treatment manipulations.

This result indicates that students who engaged in metaconceptual processes more successfully accommodated scientific views compared to students taught by traditional instruction. Examination of the two students’ responses to interview questions regarding force and motion conducted before and following the instructional interventions gives an idea about the extent of the changes in their ideas of force and one-dimensional motion. Their responses indicate that the changes in their ideas not only were at the factual level but their ideas also changed at the ontological level. For example, a major change in David’s and Lisa’s ideas was seen in their ideas regarding the natural state of objects. Prior to the instructional interventions, they believed that force or momentum was necessary to keep an object moving. After the instructional interventions, they displayed evidence that they considered objects’ constant motion as a natural state. Unlike his pre-instructional view, David did not mention any conceptual entities such as momentum or force in the direction of an object’s motion. Prior to the instructional interventions, Lisa
identified an acquired force acting on objects that were set in motion. In doing so, she made an ontological assumption about force. She considered force as an entity that can be transferred from the agent to the object. After the instructional interventions, she did not list any acquired force in the direction of objects’ motion in various situations. Lisa displayed evidence that she assigned inertia to a scientifically accepted ontological category after the instructional interventions. While she defined force as an interaction between objects, she described inertia as the “fact” that objects continue to move in a direction. She was able to state that inertia did not have an amount and could not be compared with the amount of a force. Unlike Lisa, however, David displayed evidence that he considered inertia as an entity that had an amount after the instructional interventions. He associated inertia with the speed of the object. For him, the inertia of an object increased as the object speeded up and it decreased as the object slowed down. On the other hand, he stated that he no longer considered inertia as a force and he did not compare the amount of force and inertia during his explanations of the motion of objects as he did before the instructional interventions. Prior to the instructional interventions, neither David nor Lisa showed any signs of knowledge about the outcome of balanced and unbalanced forces. They believed that force in the direction of objects’ constant motion had to be greater than the force acting on the objects in the opposite direction. After the instructional interventions, both of them displayed evidence that they accommodated a scientific view about balanced and unbalanced forces. They both maintained that the forces acting on the objects had to be equal in order to keep them moving at a constant speed.
The statistical difference found between the conceptual understanding of experimental and control groups should be interpreted carefully. In the experimental group, various types of instructional activities were used to facilitate students’ engagement in different types of metaconceptual processes, while students in the control group were taught the same science content with traditional instruction. Metaconceptual processes in their nature are internal and may not always need external prompts, though one’s engagement in metaconceptual processes, especially sophisticated ones, is more likely to occur when they are externally prompted. Therefore, it cannot be said that students in the control group who were taught by traditional instruction did not engage in any metaconceptual processes. However, it is appropriate to say that students in the experimental group were facilitated to engage in a wide range of metaconceptual processes that had higher frequency and higher level of sophistication compared to those of the students in the control group. The data about metaconceptual processes of three students presented in Chapter 4 serve as evidence for the experimental group students’ engagement in processes ranging from simple awareness of the content of ideas to more sophisticated metaconceptual thought. They reported that they had been never asked to think about their initial ideas in science classes they had taken before. Even simple awareness of initial ideas was a new learning experience for these students. This indicates that even simple awareness of one’s ideas needs to be facilitated with formal instructional opportunities that was provided with using metaconceptual teaching activities in the experimental group. To come to the point, the difference between experimental and control groups in their conceptual understanding cannot be attributed to the lack of control group students’ metaconceptual processes but, rather, it should be attributed to the
facilitation of metaconceptual thought in the experimental group, and consequently, to experimental group students’ engagement in metaconceptual processes in a more frequent and more sophisticated way.

To sum up, the facilitation of metaconceptual processes had a significantly more positive impact on improving students’ conceptual understanding compared to the effect of traditional instruction. This finding strengthens the theoretical claims about the positive role of metacognition in science learning (e.g., Davis 1996; Thomas & McRobbie 2001) and also the case in favor of introducing instructional activities used to facilitate students’ engagement in metaconceptual processes in classroom settings. Although this study gives signs of the positive impact of facilitating metaconceptual processes on students’ conceptual understanding, this finding should not be treated as a causal-relationship between students’ engagement in a particular type of metaconceptual process and the changes in their ideas. To date, the nature of the mechanisms of this relationship has not been fully identified. Thus, this result should be treated as a sign for the relative effect of facilitating various types of metaconceptual processes in comparison to effect of using traditional instruction on students’ conceptual understanding.

**Question 2: Durability of the Impact of Metaconceptual Teaching Practices on Students’ Conceptual Understanding**

The second question in this study focuses on the durability of the relative effectiveness of metaconceptual teaching activities on students’ conceptual understanding. In other words, this research question aims to answer whether the difference between the experiments and control groups that was found following the
instructional interventions was maintained nine weeks after the instructional interventions or experimental group students’ conceptual understanding dropped to the level of the control group students. In order to provide answer to this research question, the experimental group’s mean scores on delayed-FCI were compared with that of the control group by using ANCOVA. Delayed-FCI was administered to both groups nine weeks after instructional interventions ended. Students’ pre-instructional FCI scores were used as the covariate to adjust students’ delayed-FCI scores for the differences in students’ conceptual understanding that existed prior to the instructional interventions.

The ANCOVA generated to compare experimental and control groups on their delayed-FCI scores, resulted in a significant F value (F=11.33, p<.05), indicating a significant mean difference in favor of the experimental group. When the differences in students’ conceptual understanding before the instructional interventions were statistically controlled, students in the experimental group significantly outperformed those in the control group even after a nine week period. This result indicates that the experimental group’s students’ FCI scores did not drop to the level of control group students who had a higher number of alternative ideas. They maintained their relatively better conceptual understanding nine weeks after the instructional interventions. This result indicates that metaconceptual teaching interventions not only had significant positive impact following the instructional interventions, but the positive difference in favor of the experimental group lasted for nine weeks. This result implies that providing students with structured opportunities to engage in various types of metaconceptual processes not only helped students gain greater scientifically accepted content knowledge following the instructional interventions, but it also gives signs of an enduring positive
impact. The long-term impact of facilitating metaconceptual processes on students’ conceptual understanding was also reported in Blank’s study (2000), in which students were given formal opportunities to talk about their science ideas.

Students’ regression to their alternative ideas is an important problem in science learning (Georghiades, 2001). The fact that experimental group students demonstrated a better performance on the FCI even after a nine-week period compared to the control group gives signs of the relative effect of metaconceptual processes in preventing the reappearance of students’ alternative ideas. Vosniadou (2003) maintained that learning of individuals who are metaconceptually aware of their ideas, presuppositions, and the changes in their ideas is less “fragile.” In this study, students in the experimental group were facilitated not only to become aware of their ideas and ontological presuppositions, but also to monitor changes in their ideas. Individuals who monitor the changes in their ideas are likely to acquire information about the validity of their current and previous ideas and their justifications for the changes in their ideas. Students who were the focus of the case studies reported that their well-formed initial ideas about force came into their mind when they were asked to provide explanations for a situation. However, when they think of their initial ideas, they were able to activate the information about the invalidity of their initial idea. This information prevented them from using their initial ideas to explain the situation. This finding of this study suggests that facilitation of metaconceptual processes leads to retaining and using correct ideas for a longer time period.
Question 3: Nature of Metaconceptual Processes

One of the aims of this study was to tease apart and categorize the types of metaconceptual processes, portray the trends in each metaconceptual process, and describe the nature and the content of the metaconceptual processes that students engaged in as they participated in the metaconceptual teaching activities. In this study, this goal was accomplished in two steps: In the first step, the types and the science content of metaconceptual processes that are related to the science ideas of two students selected from the experimental group were described. Force and one-dimensional motion were selected as the content area to study each individual case study student’s metaconceptual processes. Students’ science ideas prior to and after the instructional interventions were examined and the changes in their ideas were summarized. Then, each student’s metaconceptual processes about those ideas were portrayed by focusing on the types and science content of those processes. In doing so, it was not the intention of this study to explore a one-to-one causal relationship between the observed changes in students’ ideas and any particular metaconceptual process but, rather, the intention of this study was to identify the types and content of students’ metaconceptual processes that they engaged in while encountering science ideas that changed in students’ minds after the instructional interventions. In the second step, each type of the metaconceptual processes was described by providing examples from three students and from all content areas covered throughout the instructional interventions. In explaining the types of metaconceptual processes, the trends observed within each type of process are described and interdependent relationship (prerequisite relationship) among the various types of processes are depicted.
Types of Students’ Metaconceptual Processes

In this portion of this section, the findings regarding the types and the nature of metaconceptual processes that each student engaged in are briefly summarized by giving examples and the trends observed within each type of metaconceptual process are described. In explaining the trends within each metaconceptual process, findings that resulted from not only David and Lisa’s data but also Kelsey’s data are provided, if necessary. After summarizing the findings, conclusions drawn from the findings of this study are outlined.

In this study, the three case study students displayed evidence for their engagement in three main types of metaconceptual processes: metaconceptual awareness, metaconceptual monitoring, and metaconceptual evaluation. Within each type of metaconceptual process, sub-categories that are qualitatively different in terms of the object of the process and information generated from the process were observed. Within metaconceptual awareness, evidence for two types of awareness was found: first-order metaconceptual awareness and second-order metaconceptual awareness. The findings within each type of metaconceptual process are summarized below.

First-Order Metaconceptual Awareness. In this study, each individual case study student’s metaconceptual processes about their ideas that were identified prior to and after the instructional interventions were described. Both Lisa and David had low scores on the pre-instructional FCI indicating various alternative ideas. Their pre-interview responses also showed that they had several alternative ideas about force and motion that were congruent with those reported in the literature. Even though David had taken a
physics course before this study, like Lisa, he possessed a variety of alternative ideas about force and one-dimensional motion. Throughout the instructional interventions, as David and Lisa participated in the metaconceptual teaching activities, they were able to become aware of almost all of their alternative ideas that were identified prior to the instructional interventions. This result suggests that when case study students were provided with proper instructional activities they did not have difficulty in becoming aware of the ideas that they brought into the classroom settings. As Lisa and David engaged in a variety of activities in the form of journal writing, group-based activities and classroom discussions, they made their ideas explicit through verbal and written comments and graphical representations. They not only made reference to the ideas identified prior to the instructional interventions, but also to the ideas that they constructed throughout the instructional interventions. For example, David made his idea of “residual force” (force imparted in the objects after they are set in motion) explicit in a class discussion. For Lisa, Kelsey, and David, becoming aware of what they know was a new learning experience. They maintained that they had never been asked before to think about their ideas before they were introduced to a new concept. This finding suggests that, for these students, the engagement in even simple awareness of their ideas required structured instructional opportunities that enabled them to think about their ideas.

Throughout the instructional interventions, David and Lisa displayed evidence that their awareness of their personal stock of information was not limited to their ideas about a given situation; but, rather, they displayed evidence for their recognition of the elements of their conceptual ecology. They became aware of the elements of their conceptual ecology either when they provided explanations for the given situations in
order to deal with the demands of the instructional activities or when they provided justifications for ideas. For example, they became aware of the contextual differences in the form of making comparisons of the forces acting on objects based on the environmental characteristics of situations (frictionless surface vs. surface with friction), characteristics of objects (light objects vs. heavy objects), and types of motion of objects (objects moving at a constant speed vs. objects moving at an increasing speed). Although both David and Lisa made reference to the differences in the motion of objects on a frictionless surface and on a surface with friction, David displayed an ability to use this information to justify his idea that force was not needed to keep an object moving on a frictionless surface. For him, objects on a surface with friction slowed down due to the opposing force. On the other hand, objects on a frictionless surface did not have to counteract any force and kept moving without a need for a force in the direction of its motion. Unlike David, Lisa simply stated that objects on a frictionless surface would slow down in response to a journal prompt. While David used the information generated from his awareness of contextual differences to justify his ideas, Lisa’s recognition of the contextual differences stayed at the awareness level. This finding points out the differences in these two students’ engagement in first-order awareness process.

David and Lisa also displayed evidence for their ability to use their experiences to justify ideas. However, in some instances as they became aware of their experiences, they displayed evidence that they did not interpret them in the way the scientists do or they used inappropriate experiences to justify an idea. For example, David made reference to an experience in which an object was accelerating to support his claims about the amount of force required to move an object at a constant speed. Similar to David, Lisa
misinterpreted her experience about colliding objects. For her, since a moving object caused another object to move after a collision, force had to be transferred from the moving object to the other object. Lisa used her experience about colliding objects to justify her ontological claims about the transferability of force from the agent to the object.

Both Lisa and David became aware that they did not have enough information to provide explanations for the given situation or that they did not know some conceptual entities as they discussed their ideas. Having taken a physics course before, David was familiar with the word “momentum.” However, due to his idea that something had to keep an object moving, he considered momentum as an entity that was responsible for the objects’ motion. During their discussions about forces acting on an object sliding on a frictionless surface, they realized that they did not know whether momentum was a force. Lisa also became aware that she did not know the definition of force and did not possess enough information to justify her ideas. David displayed evidence that his realization of what he did not know enhanced his intention to learn the concepts that he did not know and made him pay more attention to those conceptual entities as he was introduced to them. Like David, Lisa’s awareness that she did not have adequate knowledge to explain a given situation made her pay attention to the content of the group discussion. This finding indicates that these two students’ awareness of what they did not know promoted their intention to learn the conceptual entities missing in their conceptual structure.

Vosniadou and Ioannides (1998) maintained that students are usually not aware of their ontological presuppositions. In this study, both Lisa and David displayed evidence for their ability to become aware of their ontological presuppositions about forces and
force-related entities. For example, David differentiated “residual force” (force imparted into objects after they are set in motion) from applied force. He also made reference to the ontological characteristic of force when he stated that the amount of forces did not change as objects moved in the air. Lisa also became aware of her ontological presuppositions about force. She realized that she considered force as an entity that can be transferred from one object to another. She also recognized her ontological presupposition that objects could not move without forces acting on them. Both students displayed evidence that they differentiated inertia from force. They explicitly stated that they did not consider inertia as a force. Unlike David, however, Lisa displayed an ability to distinguish ontological characteristics of force and inertia. She revealed that she considered inertia as a property of objects, while she considered force as an interaction between objects. Unlike David, she was also able to differentiate the outcome of these two entities. She was aware that objects continued to move at a constant speed due to their inertia and they accelerated due to forces acting on them. Kelsey, on the other hand, engaged in first-order metaconceptual awareness of her ontological presupposition about force by stating that force is not transferred from one object to another. In doing so, she did not make ontological comparisons between entities. This finding indicates that these case study students’ awareness of their ontological presuppositions showed variations and occurred at different levels of sophistication. For example, although at some points they directly made reference to the ontological characteristics of one entity, at other points they displayed evidence of their ability to differentiate ontological characteristics of more than one conceptual entity. Theoretically, individuals who become aware of their
scientifically unacceptable ontological presuppositions and differentiate them with scientifically accepted ones may be more likely to change their alternative ideas.

Second-Order Metaconceptual Awareness. Both David and Lisa displayed evidence of their engagement in another type of metaconceptual awareness. They were able to make reference to ideas or elements of their conceptual ecology that they had in the past. At various points, as they participated in the instructional activities, they became aware of the ideas that they had prior to the instructional interventions and they formed during the instructional interventions. For example, both Lisa and David were aware that they initially defined force as energy. They made reference to their initial ideas regarding the need for a net force in the direction of objects’ constant motion. They also recognized that they initially associated motion with force. David made reference to his initial idea that force was needed for objects’ motion. Lisa was aware of her initial idea of an acquired force imparted into objects after they were set in motion. David also recognized his initial idea that continuous exertion of a force caused the object move at a constant speed. Their awareness of their initial ideas indicates that they were able to monitor those ideas at the time they made those ideas explicit. For the case study students, their awareness of their past ideas was critical for them to monitor changes in their ideas, as monitoring changes in one’s idea required them to compare their past ideas with their current ideas.

diSessa (1993) maintained that novice learners use case-based, self-explanatory knowledge pieces to explain a phenomenon. Unlike scientific principles, these phenomenological primitives are context-dependent and fragmented. Students’ ability to
become aware of the use of their ideas in different contexts is important for noticing the inconsistencies in their conceptual structure, hence promoting internally consistent and coherent conceptual systems. In this study, both David and Lisa displayed evidence of their ability to recognize and compare their use of ideas in different contexts, namely, their ability to engage in second-order awareness of the contextual differences. For example, David compared his initial idea about the dissipation of residual force across different situations (surface with friction vs. motion in the air). He was aware that he pictured residual force (force imparted into objects after they are set in motion) as an entity reduced by an opposite force. He realized that he imagined it as being reduced by friction when the object was moving on a surface with friction, and he pictured it as being reduced by gravity when the object was moving in the air. Lisa, on the other hand, compared her initial idea regarding the comparative amount of forces needed to keep an object moving for situations where objects were moving at a constant speed and at increasing speed. She realized that for both situations she held the same idea (unbalanced forces were needed to keep an object moving). She was aware that she could not make a distinction between the amount of forces needed to keep an object moving at a constant speed and at increasing speed. It is clear that while David compared his ideas across similar contexts where there was an opposite force, Lisa compared her ideas across different situations where the type of the motion of objects made a difference in terms of the comparative amount of forces needed to keep objects moving. Although Lisa recognized her problematic use of the same idea for different situations, David’s comparison of his initial ideas across different contexts did cause him to realize any inconsistencies in his ideas due to the similarity in the contexts. In this study, David, Lisa
and Kelsey displayed evidence that they acquired knowledge about the generalizability of the scientifically accepted views to all contexts. David explicitly stated that his initial ideas did not work in all situations. David, Lisa, and Kelsey reported that one way of checking the validity of competing ideas was to apply it to different contexts. It is clear that students who display this ability may be more likely to detect the inconsistencies in their ideas, and construct more generalizable ideas.

After Lisa ad David acquired scientific views about force and motion, they were able to make reference to the ideas that were missing in their conceptual structure. For example, David became aware that he did not know initially the difference between the outcomes of balanced and unbalanced forces. Similarly, Lisa engaged in second-order metaconceptual awareness of what she did not know when she realized that she did not know the difference between the types of motion resulted from objects’ inertia and unbalanced forces. Theoretically, one’s awareness of what she or he did not know in the past potentially gives her or him an idea regarding the limitations of one’s past conceptual structure. Thus, individuals who are aware of the limitations of their past conceptual structure would be more likely to keep their current concepts for longer times.

As both Lisa and David revealed that they initially did not differentiate inertia and force considered inertia as a force, they became aware that they previously assigned inertia and force to the same ontological category. In doing so, they engaged in second-order awareness of ontological presuppositions.

*Metaconceptual Monitoring.* The case study students’ ability to engage in second-order metaconceptual awareness of their ideas, ontological presuppositions and what they
did not know before was a minimum requirement for their engagement in monitoring changes and ontological shifts in their ideas. Vosniadou (2003) pointed out the importance of monitoring changes in ideas in promoting the durability of students’ ideas. Both Lisa and Kelsey displayed evidence that they acquired information regarding the validity of their initial and current ideas as they monitored their ideas. They used this information when their initial ideas reappeared in their minds. When their well-formed initial ideas reappeared in their mind, they simply remembered that their initial views were incorrect and that they changed them with scientifically accepted ideas. These students’ engagement in this process prevented them from regressing to their initial ideas. Both Lisa and David displayed evidence of their ability to monitor several changes in their ideas. Both students recognized that they did not initially differentiate the amount of forces acting on objects moving at a constant speed and at an increasing speed. They realized their initial idea that unbalanced forces were needed to keep objects moving regardless of the type of motion. They monitored changes in their ideas when they compared their currently acquired knowledge about the outcome of balanced and unbalanced forces with their initial ideas. David and Lisa were also able to monitor the ontological shifts in their ideas. For example, David was able to state that he no longer considered inertia as a force. He was aware that his initial idea of “residual force” was called inertia by scientists. Similar to David, Lisa was also able to monitor the change in her initial idea of acquired force with inertia. For her, the change in her initial idea of acquired force with inertia was a “word-game.” She was aware that her initial idea of acquired force was defined as inertia by scientists. Lisa displayed evidence for monitoring the ontological shift in her ideas when she became aware of her initial idea of
acquired force and made an ontological distinction between force and inertia (force is interaction, inertia is a property).

Both Lisa and David not only acquired information about their cognitive state through monitoring the changes in their ideas but also through monitoring their understanding of new ideas. One of the conditions of conceptual change presented in CCM is the intelligibility of the new conception. Before conceptual change takes place the learner must understand the meaning of the new conception (Posner et al., 1982). Both David and Lisa monitored their understanding of Newton’s First Law. While David checked his understanding of this law by restating it in his own words, Lisa claimed that she checked her understanding of the Law by using it in explaining different situations. Although both students claimed that they understood Newton’s First Law, David’s statement of the law showed that his understanding of the Law was not congruent with the Newtonian view. This finding indicates that David’s engagement in monitoring understanding of an idea in the form of stating the Law in his own words did not guarantee that they had a correct understanding of that idea. David’s failure to understand why objects fall to Earth at the same time encouraged him to rethink the phenomenon. This result indicates that David’s recognition of his failure to understand a concept enhanced the likelihood of his dissatisfaction with his current state of cognitive functioning. This dissatisfaction promoted his tendency to invest an effort to understand the new information.

David and Lisa not only recognized their personal stock of information, but they were also able to monitor other people’s ideas. Their engagement in this type of metaconceptual process was seen when they clearly referred to the content of their
classmate’s ideas. Their ability to monitor the content of other people’s ideas became more sophisticated when they compared that information with their existing ideas. For example, Lisa monitored David’s idea that there were no forces acting on objects after they lost contact with the agent. She was able to monitor the inconsistency between her initial idea of acquired force and Newton’s First Law. At the time David believed that motion of objects was caused by residual force, he monitored his classmate’s idea that motion of objects was caused by a force. As he compared this idea with his own idea, he engaged in monitoring the consistency between his existing idea and ideas of other people. The content of David and Lisa’s monitoring of other people’s ideas suggests that learners not only monitor scientifically acceptable views, but also scientifically unacceptable views of other people. David and Lisa not only monitored the consistency of their existing ideas and ideas of other people, but they also compared the consistency of their own ideas with information generated from their observations. For example, David was able to compare his predictions with his observations of the demonstrations about Newton’s Third Law. In order for learners to consider changing a conception, they must be dissatisfied with their existing conceptions (Posner et.al, 1982). Dissatisfaction with an existing conception can be experienced when the existing ideas do not explain an anomalous event. In order to experience a cognitive conflict, however, learners should first realize the differences between what they know and what they observe (Limón, 2001). Theoretically, students who monitor the discrepancies between their existing ideas and ideas of other people or information generated by their observations may be more likely to reconsider their existing ideas and try to find justification grounds for their own ideas or for the information coming from other sources.
Another qualitatively distinct metaconceptual process that Lisa and David engaged in throughout the instructional interventions was metaconceptual evaluation. They displayed evidence for their ability to make judgmental comments about why an idea explained the situation better than another idea. They not only made judgmental decisions about the validity of ideas, but they also provided justifications for them. As Lisa and David engaged in this processes, they made comments about the relative plausibility and usefulness of competing ideas, or they chose one idea among several alternatives along with providing justifications for the chosen idea. According to Hewson (1981), conceptual change cannot occur without concomitant changes in the relative status of competing concepts. He suggested that the status of the new conception and the status of the existing conception together determine whether learners consider changing a conception that they hold. Thus, learners’ decisions about the plausibility and fruitfulness of competing conceptions are critical in the process of changing their conceptions. In order to make reference to the plausibility of an idea, Lisa and David used expressions such as “makes more sense,” “believable,” “truly odd,” “attractive,” and “have faith in.” They also evaluated ideas by explicitly stating that an idea was right or wrong and providing reasons or justifications for the validity of ideas. As David evaluated ideas, he drew on his existing knowledge, ontological presuppositions, or experiences. For example, in order to show the invalidity of his classmate’s idea that forces were balanced at the peak of the trajectory of a ball tossed up, he made reference to his knowledge about balanced and unbalanced forces. Similarly, he justified his ideas by revealing his ontological presupposition that the amount of forces did not change as objects moved in the air. In order to support his claims that there was
no need for a force to keep an object moving on a frictionless surface he drew on his past experience with hockey pucks. Likewise, Lisa drew on her experience about colliding objects to describe why her idea of acquired force better explained the motion of an object sliding on a frictionless surface.

The case study students in this study also reflected on the plausibility of ideas without explicitly providing justifications for them. For example, although Lisa stated that she found David’s idea that there was no force acting on objects sliding on a frictionless surface plausible, she could not provide any reason for why she found that idea believable. Throughout the group discussions, compared to Lisa, David provided more justifications for the ideas that he defended. This result suggests that the case study students’ engagement in metaconceptual evaluation occurred at different degrees of sophistication based on their ability to justify ideas by using their existing knowledge, presuppositions, experiences, and experimental evidence.

Lisa also evaluated ideas by commenting on the relative usefulness of Newton’s Laws compared to her own ideas. For Lisa, the ideas presented in Newton’s Laws were clearer, easier to use, and could distinguish fundamental concepts such as inertia and force based on the type of motion of the objects.

As the case study students metaconceptually evaluated competing ideas, they made judgmental decisions based on different criteria. As the examples provided above indicate, Lisa and David used their existing ideas, ontological presuppositions and experiences in deciding on the validity of ideas. Experimental or observational evidence served for them as factual evidence to make judgment decisions about ideas. Lisa, David, and Kelsey displayed evidence that they considered ideas that were generalizable to all
situations as valid. Having this epistemological belief, they thought of situations in which competing ideas did not work.

The conclusions drawn from the findings described above are summarized in terms of the general characteristics of metaconceptual processes, trends observed within each type of metaconceptual processes, and individual student’s ability to engage in metaconceptual processes.

*General Characteristics of Metaconceptual Processes*

The analysis presented in Chapter 4 demonstrated that metaconceptual processes have the following characteristics:

*Metaconceptual processes are multidimensional.* Similar to the overarching construct metacognition, metaconceptual thought covers different types of processes. Within each main type of metaconceptual process (i.e., metaconceptual awareness, metaconceptual monitoring, metaconceptual evaluation), several variations were observed. Each qualitatively distinct process differs from another one in terms of the object of the metaconceptual thought and/or the information generated from the metaconceptual process. For example, in the case of first-order metaconceptual awareness of one’s ideas, the object of the process is one’s current ideas while in the case of first-order awareness of one’s experiences the object of the process is one’s past experiences. Similarly, in the case of monitoring one’s understanding of a new idea, the object of metaconceptual thought is a new idea, while the object of metaconceptual thought in the case of first-order metaconceptual awareness of ontological presuppositions is one’s ontological presuppositions. While the former generates
information regarding one’s success and failure in understanding a concept, the latter generates information about one’s existing conceptual system.

Metaconceptual processes are multifaceted and interdependent. Some of the metaconceptual processes are multifaceted in the sense that they involve one’s engagement in more than one type of process. For example, monitoring changes in one’s ideas involves engagement in both first-order and second-order metaconceptual awareness of ideas. Metaconceptual processes are also interdependent in the sense that one metaconceptual process serves as a prerequisite of the other processes. It is clear that all multifaceted metaconceptual processes are interdependent. For example, first- and second-order metaconceptual awareness are prerequisites of monitoring changes in ideas. However, in the case of second-order metaconceptual awareness, although it is not multifaceted (it does not involve more than one metaconceptual process), first-order metaconceptual awareness is prerequisite of second-order metaconceptual awareness, as in order to make reference to an initial idea learners should make that idea explicit at a time and they should monitor that idea at the time they make reference to that idea. When the prerequisite relationship between different types of metaconceptual processes is examined (see Figure 4.2 in Chapter 4), it can be seen that one’s engagement in first-order metaconceptual awareness plays a critical role in one’s engagement in various types of metaconceptual processes, namely, second-order metaconceptual awareness, monitoring changes in ideas, monitoring consistency between existing ideas and new information, and monitoring consistency between existing ideas and new experience.

Metaconceptual processes occur at different levels of sophistication. Some types of metaconceptual processes are more sophisticated than other ones in the sense that
sophisticated ones demand an action on the less sophisticated ones or require more abstract thinking. Monitoring the consistency between new and existing idea, for example, requires the learner to make a comparison between one’s existing idea and new information coming from another source. In doing so, the learner not only engages in first-order awareness of the content of his/her idea and monitoring new information coming from other people, but s/he also compares the information generated from these processes. In that sense, monitoring the consistency between existing and new ideas is a more sophisticated process than first-order metacognitive awareness of ideas and monitoring ideas of other people. Metacognitive evaluation involves learners in commenting on the status of competing ideas, noticing the limitations and implications of ideas, drawing inference about ideas, and providing justifications for the validity of ideas. These processes demand more abstract thinking than simply articulating the content of ideas about the natural world. The level of the sophistication of metacognitive processes may make a difference in the automaticity the process. Metacognitive processes that require more abstract thinking or an action on other metacognitive processes are less likely to occur automatically but require purposeful thought process.

Trends in Each Metacognitive Process

In this study the following trends and characteristics were observed within each type of metacognitive process:

- Both Lisa and David engaged in first-order metacognitive awareness either to provide explanations about a given situation as they deal with the demands of
instructional activities or to provide justifications for competing ideas based on what they knew, their ontological presuppositions, and experiences.

- Lisa and David engaged in a particular type of metaconceptual process at different levels of sophistication. Hence, different levels of sophistication were observed not only across different types of metaconceptual processes but also within a particular metaconceptual process. For example, David and Lisa displayed evidence that they either made reference to the ontological characteristics of one entity (e.g., force) or they compared the ontological characteristics of more than one entity (e.g., force vs. inertia) as they engaged in the first-order metaconceptual awareness of their ontological presuppositions.

- As Lisa and David engaged in first-order metaconceptual awareness of their experiences, they did not interpret their experiences in the way the scientists do or they used inappropriate experiences to justify their ideas (e.g., drawing on a experience in which force is required to accelerate an object and using this experience to explain the amount of force required to keep an object at a constant speed.)

- Lisa’s and Kelsey’s engagement in monitoring changes in their ideas generated information about the validity of their current and initial ideas. This information was activated when their initial ideas reappeared in their minds and prevented them from using their initial ideas.

- Learners’ engagement in first- and second-order awareness of contextual differences may enhance the likelihood of detecting inconsistencies in their conceptual structure. However, students may compare their ideas across contexts.
that share the same conceptual variable. For example, David compared his initial idea of residual force in two contexts in which there was an opposite force in the direction of the object’s motion (e.g., surface with friction vs. in air). Lisa realized that she had the same idea for two contexts that differed in terms of the amount of force needed to move an object (i.e., unbalanced forces are needed for keeping the objects move at constant speed and at increasing speed). The case study students were more likely to detect their problematic use of ideas or inconsistencies in their use of ideas when they compared their use of ideas across contexts that differed in terms of some conceptual entities (e.g., frictionless surface vs. surface with friction; forces acting on objects moving at constant speed vs. forces acting on objects at increasing speed).

- David’s engagement in monitoring his understanding of an idea did not guarantee that he had a scientifically accepted understanding of the ideas. However, his realization of his failure to understand an idea enhanced the likelihood of his dissatisfaction with his current state of functioning and promoted his tendency to understand the idea. Similarly, David’s and Lisa’s awareness that they did not know a conceptual entity promoted their intention to pay attention to the conceptual entities when introduced to them.

- The nature of the conceptions or content area made a difference in the types of the metaconceptual process that the case study students engaged in. For example, in this study as David and Lisa encountered Newton’s First Law, they became aware of their ontological presuppositions. On the other hand, when they
encountered the notion of balanced and unbalanced forces they did not make reference to their ontological presuppositions.

- As David, Lisa, and Kelsey evaluated ideas, they justified ideas based on different criteria. They used their existing ideas, ontological presuppositions, experiences, and experimental evidence when they made decisions about the validity of competing ideas. Their epistemological beliefs about the generalizability of ideas also served as a criterion for metaconceptual evaluation process. David, Lisa, and Kelsey explicitly stated that ideas that worked in all situations are valid. As they juxtaposed competing ideas, they tried to think of a situation where one idea did not work.

**Students’ Ability to Engage in Metaconceptual Processes**

In this study, each of the two students’ metaconceptual processes that they engaged in throughout the implementation of metaconceptual teaching interventions were portrayed. The findings summarized above and results presented in Chapter 4 give an idea about not only the abilities of each individual case study student but also the differences in the abilities of two students to engage in metaconceptual processes. The data analysis of two individual case students supports the following conclusions:

- When students were provided with appropriate formal opportunities, Lisa and David did not have difficulty becoming aware of the alternative ideas that they brought into the classroom. Throughout the metaconceptual teaching interventions, both David and Lisa became aware of almost all of their alternative ideas that were identified prior to the instructional interventions.
• Both Lisa and David displayed an ability to engage in a variety of metaconceptual processes ranging from simple awareness of their ideas to more sophisticated higher-order thought processes.

• The level of sophistication at which each individual student engaged in a particular type of metaconceptual process differed from one context to another. For example, while Lisa was able to provide justification as she reflected on the plausibility of an idea in one context, she did not provide any justifications as she evaluated the same idea in another context.

• In a particular context, the frequency and the level of sophistication of a particular metaconceptual process differed from David to Lisa. For example, in a group discussion about forces acting on an object sliding on a frictionless surface, David provided more justifications as he evaluated ideas than Lisa, who reflected on the plausibility of David’s ideas without providing any reasons. This, however, does not mean that Lisa lacked the ability to provide justifications when she evaluated ideas. Similarly, in a particular context, engagement in a sophisticated type of metaconceptual process (categorically different types of metaconceptual processes, e.g., first-order awareness of ideas vs. metaconceptual evaluation) differs from one student to another. For example, in a group discussion about forces acting on a ball that is tossed up, David engaged in metaconceptual evaluation, while Kelsey only articulated her ideas at the first-order metaconceptual level.

Collectively, the above claims support the conclusion that engaging in metaconceptual processes is not an “all-or none” phenomenon. The case study students engaged in
several types of metaconceptual processes. The data presented in Chapter 4 show that both Lisa and David engaged in all types of metaconceptual processes throughout the instructional interventions. This means that, when appropriately facilitated, they engaged in different types of metaconceptual processes, indicating that those metaconceptual processes were in their repertoire of learning behaviors. However, the content, the frequency, or the level of their sophistication of their metaconceptual processes varied from one context to another.

Instructional Implications

Several important instructional implications can be drawn from the results of this study. One significant finding of this study is the positive short- and long-term impact of facilitating students’ metaconceptual processes on their conceptual understanding in comparison to the effect of traditional instruction. This finding strengthens the case in favor of introducing instructional activities used to facilitate students’ engagement in metaconceptual processes into classroom settings. In this study, the teaching-learning environment created in the experimental group through the use of metaconceptual teaching activities was in direct contrast with the pedagogical practices that simply requires students to sit passively, listen to the teacher, and memorize facts about the physical world. As students participated in the metaconceptual teaching activities, they actively took responsibility for making their ideas and presuppositions public in multiple ways, comparing and contrasting different ideas, providing justifications for them, reflecting on the plausibility and usefulness of competing ideas, checking the inconsistencies between their personal stock of information with information coming
from different sources, noticing the limitations of their ideas, making reference to their initial ideas, and comparing them with their current understanding.

Students’ engagement in various types of metaconceptual processes put a great deal of responsibility on the shoulders of teachers. Teachers should create a rich learning environment in which students’ metaconceptual functioning is as valued as their cognitive processes. Facilitating metaconceptual processes should be an explicit educational goal and integrated into the science curriculum. Facilitating the above stated thought processes is not a straightforward teaching practice by any means. Encouraging students to engage in metaconceptual processes requires a significant time to be set aside by teachers to promote higher order functioning and extensive effort by students to reflect on their thinking process.

In this study, several types of instructional activities were used in an integrated way to facilitate students’ engagement in different types of metaconceptual processes. Activities, such as poster drawing and journal writing were used not only to help students make their ideas explicit but also to serve as a permanent record of students’ ideas so that students could be aware of their initial ideas and explicitly compare them with their current ideas. With these characteristics, these activities can be used to help students become aware of their ideas, presuppositions, and their use of ideas in different contexts and monitor changes in their ideas. In this study, students’ journal entries involved rich examples that displayed students’ engagement in a variety of metaconceptual processes, ranging from awareness of their ideas to more sophisticated metaconceptual thought processes. Journal writing can be used as a powerful means to facilitate metaconceptual thought without interrupting the teaching sequence, especially when teachers have
concerns about the shortage of time in covering the science content. Group-based activities and whole-class discussions can be used in a powerful way to bring students’ ideas at the conscious level and help students question their knowledge claims, justify their ideas, and notice strengths and weaknesses of their ideas. In implementing these activities, teachers should use appropriate prompts that help students notice the inconsistencies in their knowledge claims and those of other students and scientists.

One of the criteria that students used in evaluating ideas was their epistemological belief regarding the generalizability of valid ideas. For them, ideas that were applicable to all situations were correct. Having this belief, they attempted to find a situation in which competing ideas did not apply. This finding suggests that teachers should provide students with opportunities to apply their ideas in different contexts. Encouraging students to make comparisons between their use of ideas in different contexts would also enhance the likelihood of detecting inconsistencies in their ideas.

The interdependent and multifaceted nature of metaconceptual processes suggests that students’ engagement in particular types of processes involves or necessitates their engagement in other types of metaconceptual processes. The case study students’ awareness of their ideas and elements of their conceptual ecology played a direct and indirect critical role in their engagement in various other metaconceptual processes. Therefore, students’ ideas and presuppositions should be an integral part of classroom discourse and written classroom artifacts.

Teachers’ ability to accommodate metaconceptual thought processes in their instruction may be closely related to their knowledge about the nature of metaconceptual processes and conceptual change. Teachers education programs have great responsibility
to provide teachers with knowledge, skills and resources about metacognition if we want metaconceptual processes to find their way into science classrooms.

Implications for Educational Research

Taxonomies of a construct clarify and isolate components that are distinguishable on some particular characteristics and functions. With this nature, taxonomies are capable of enhancing researcher’s understanding of a construct and promoting communication among them. One of the outcomes of this study is a multidimensional taxonomy of metacognitive processes that are related to and acting on learner’s conceptions. Although various taxonomies about metacognition have been proposed in the literature, metacognitive knowledge and processes that are related to or acting on one’s conceptual system have not been well-clarified in those taxonomies. Clarifying and distinguishing metacognitive processes that are acting on one’s conceptions, namely, metaconceptual processes may potentially promote communication among researchers who are interested in conceptual learning, and, hence, the productivity of research practices which aim to study the role of metacognition in the conceptual change process. The classification scheme developed in this study is a beginning point. In this regard, I am conscious that it may convey an incomplete representation of all the metacognitive processes that are critical for conceptual change, but it is potentially useful for stimulating additional research in science education.

One of the problems in studying metacognition is the difficulty in assessing students’ metacognitive processes. This practical obstacle is caused by the fact that metacognition is an internal and “in the moment” process. Having these properties, it is
difficult to measure metacognitive processes through interviews and questionnaires because students fail to remember their metacognitive events (Garner, 1987). It is impractical to use think-aloud strategy in investigating students’ metacognitive processes in classroom settings. In this study, students’ metaconceptual processes were assessed by their journal writings and audio-recordings of students’ group and classroom discourse. These assessment techniques were in harmony with the aim of this study, namely, facilitating students’ metaconceptual processes, and did not interrupt the implementation of instructional activities. Thus, this study provides a demonstration of assessing students’ online and “in-the-moment” metaconceptual processes without interrupting their ongoing metacognitive functioning and also the teaching sequence.

Recommendations for Further Research

The findings of this study add to our understanding about the relative effect of facilitating metaconceptual processes on students’ conceptual understanding in comparison to the effect of traditional instruction, and also about the nature of students’ metaconceptual processes. Needless to say, a great deal of theoretical and empirical work remains to be done in order to gain deeper insight into the role of higher order thinking in concept learning.

This study demonstrated the feasibility of making metaconceptual functioning an integral part of classroom instruction. In doing so, this study did not aim to teach students any metacognitive skills such as strategies for monitoring understanding, self-explanation, and self-questioning; rather, metaconceptual functioning was blended with the subject taught in an attempt to bring metaconceptual thinking and subject matter
together. Further investigations should be conducted to examine the combined and individual effects of teaching metacognitive thinking skills and facilitating metaconceptual processes on students’ conceptual understanding as well as on the changes in metaconceptual functioning.

Concept learning is a very complex process that occurs through the interactions of several constructs. Further research that investigates how motivational and social constructs such as attitudes, interest, goals, and social context interact with metaconceptual processes and conceptual change would enable us to grasp a more complete picture of concept learning.

In this study, metaconceptual thinking is facilitated in the domain of force and motion. Investigating students’ metaconceptual processes in other subject areas, specifically, controversial ones, such as evolution, and less controversial ones would demonstrate how metaconceptual processes interact with the nature of the topic. Moreover, studying the nature of metaconceptual processes within different age levels may potentially produce scientific knowledge about students’ abilities to engage in metaconceptual processes.

In this study, students displayed evidence for their ability to become aware of their use of ideas across different contexts. They also developed knowledge about the generalizability of correct ideas. Having developed this epistemological knowledge, they tried to find contexts in which an idea did not work when they evaluated ideas. These metaconceptual processes may potentially improve the consistency of students’ ideas and also their ability to transfer their ideas to different contexts. Further research that examines the effect of facilitating metaconceptual processes on the consistency of
students’ ideas across different contexts and their use of ideas in contextually different situations should be conducted to empirically support this claim.

Students come into classroom settings not only with well-form ed preconceptions about science, but also knowledge about concept learning. Their views of concept learning may influence the ways and the level of sophistication at which students engage in metaconceptual processes. Students’ views of learning may change as students engage in metaconceptual processes. With further research, an understanding of the interaction of students’ views of concept learning and their metaconceptual processes could be probed.

This study demonstrated that facilitating students’ metaconceptual functioning has a positive impact on their conceptual understanding. Although this result strengthens the claims about the positive role of metaconceptual processes in learning science conceptions, a one-to-one causal relationship between particular types of metaconceptual processes and the change in particular ideas could not be drawn from the analysis of data due to the multidimensional and multifaceted character of metaconceptual processes. It is clear that both conceptual change and metaconceptual processes are complex and occur through the interaction of several constructs. However, any theoretical and empirical attempts to investigate the nature and mechanisms of how metaconceptual processes influence and bring about change in students’ ideas would be a great addition to our understanding of concept learning.

Concluding Remarks

This study demonstrated that metaconceptual teaching interventions that aimed at facilitating students’ metaconceptual processes had a significantly positive effect on
promoting students’ conceptual understanding, compared to the effect of traditional instruction. This study also showed that this impact was not only a short-term outcome of facilitating students’ metaconceptual processes, but it endured after a nine-week period. This finding strengthens the theoretical accounts about the intertwined nature of metacognitive and conceptual change. Without knowing the mechanisms of how and in what ways metaconceptual processes influence or bring about the change in students’ ideas, however, our conceptualization of them could not go further than considering them as the “moderator” of the changes in as students’ ideas.

The findings regarding individual case study students’ metaconceptual processes showed that students had the ability to engage in different types of metaconceptual processes when they were provided with structured opportunities. In regard to the general nature of students’ metaconceptual processes, the findings indicated that metaconceptual processes are multidimensional, multifaceted, and interdependent, and they occur at different levels of sophistication.
REFERENCES


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APPENDIX A

CONSENT FORMS AND LETTERS
Dear Parent/Guardian:

Your child is invited to participate in a research study. Dr. Christopher Andersen, an Assistant Professor at The Ohio State University, and Nejla Yuruk, a doctoral student at The Ohio State University, will be conducting this study. The purpose of this study is to compare the effectiveness of two different teaching approaches in two different classrooms (experiment and control) on students’ learning of science and to better understand how children learn science. The aim of the teaching method that will be used in your child’s physics class is to facilitate your child’s awareness of his/her learning of science. Your child's physics teacher and a doctoral student from The Ohio State University are working together to design the teaching activities.

In order for the researchers to conduct the study, one of the researchers, Nejla Yuruk, will be in your child’s classroom for 9 weeks. During this time, the researcher will observe and may talk to the students. The class will be asked to be involved in learning activities such as poster drawings, journal writing, classroom and group discussions and hands-on experiments. Your child’s physics teacher is already using these learning activities as part of his regular instruction. As part of this study, your child’s physics teacher will use prompts during the implementation of the learning activities in order to facilitate students’ thinking about their science learning. We are interested in the physics teacher’s use of the prompts and how they help the students reflect on their science learning.

Classroom instruction will be videotaped. If you do not consent, the camera will be positioned so your child will not be visible in the videotapes. With your consent, pair and group discussions will be audio-recorded and photocopies of your child’s science journal writings will be made. The image of your child’s poster drawings will be video-recorded. All the video and audiotapes and the photocopies of the students’ science journal writings will be stored at a secured location only accessible to the researchers and will be destroyed upon the completion of the study.

Tests which assess students’ learning of science will be administered three times during the study. Completing of each test may take 50 minutes or less. Some students may be asked to meet with one of the researchers 2-4 times for 40 minutes or less each time to talk about their science ideas and ideas about their learning of science. Your child may also be selected to participate in the interviews, if we believe there is a need to clarify your child’s thinking about learning science. These interviews will not cause the students to miss out on regular classroom instruction. With
your consent the interviews will be audio-taped and photocopies of your child’s drawings will be made.

Your child can benefit from this study. The learning activities that will be used may help your child have a better understanding of science. The learning activities may give your child the opportunity to reflect on his/her science ideas and his/her own learning. There is no known or foreseeable risk that might be expected from your child’s participation in this study.

Your child’s participation is entirely voluntary. Your child’s grade will not be affected by his/her decision to participate or not to participate in this study. The results of this study will not be used to evaluate your child’s behavior or performance. Your child’s grade will be determined by your child’s physics teacher based on based on homework, quizzes or exams. The researchers will not be involved in giving a grade your child. Your child may withdraw any time without consequences of any kind. Should your child decide to withdraw, his/her data will be destroyed without penalty or loss of benefits as a student.

All the information collected from this study will remain confidential and will be used only for the purpose of the research. We plan to share the results of the study through publication in academic journals and presentation at academic conferences. No reference will be made in written and oral reports that could be linked to your child or to the school. The names of persons and places will be changed; pseudonyms will be used for all names of persons and places.

If you have questions about your child’s rights as a participant of this study, please contact The Office of Responsible Research Practices, Third Floor, Research Foundation Building, 1960 Kenny Road, Columbus, Ohio 43210-1063; Phone: 688-8457

We explained the purpose of this study and described what your child’s participation in the study might require. If you are willing to grant permission, and if your child is willing to participate, please sign the consent form attached to this letter and ask your child to return it to his/her physics teacher as soon as possible. It is necessary that both you and your child sign the form in the spaces indicated. Keep this letter for your records.

You may have questions or concerns during the time of your child’s participation in this study, or after its completion. If you have any questions regarding this study, please feel free to contact the researchers Dr. Christopher Andersen or Nejla Yuruk at the addresses and phone numbers provided below.

Sincerely,

Nejla Yuruk  
657 Tuscarawas Ct.  
Columbus OH 43210  
Phone: (614) 688-9126  
e-mail: yuruk.1@osu.edu;

Christopher Andersen  
Founders 2048  
1179 University Drive  
Newark OH 43055  
Phone: (740) 366-9304  
e-mail andersen.18@osu.edu.
CONSENT FOR PARTICIPATION IN SOCIAL AND BEHAVIORAL RESEARCH

Protocol Title: The Effectiveness of Metaconceptual Teaching Practices on Students’ Conceptual Understanding and Their Views of Learning

Protocol Number: 2003B0218

Researchers: Dr. Christopher Andersen (Principal Investigator)
Nejla Yuruk (Co-Investigator)

I consent to my participation in (or my child’s participation in) research being conducted by Christopher Andersen and Nejla Yuruk of The Ohio State University.

I have read and understand the information in the attached letter regarding the purpose of the study, the procedures that will be followed, and the amount of time it will take. I understand the possible benefits, if any, of my participation (and/or my child’s participation). No guarantees have been made regarding the effectiveness of the learning activities that will be used in this study.

I know that I can (and/or my child can) choose not to participate without penalty. If I agree to participate, I can (and/or my child can) withdraw from the study at any time, and there will be no penalty.

I consent to the use of audio and videotapes and my (and/or my child’s) science journal writings. I understand how the tapes and the science journal writings will be used for this study.

I have had a chance to ask questions and to obtain answers to my questions. I can contact the investigators at andersen.18@osu.edu, (740) 366-9304; or yuruk.1@osu.edu, (614) 688-9126. If I have questions about my rights as a research participant, I can call the Office of Research Risks Protection at (614) 688-8457.

I understand in signing this form that, beyond giving consent, I am not waiving any legal rights that I might otherwise have. My signature on this form does not release the investigator, the sponsor, the institution, or its agents from any legal liability for damages that they might otherwise have.

I have read this form or I have had it read to me. I sign it freely and voluntarily. A copy has been given to me.

Print the Name of the Participant

Signed: _____________________________ Date: ____________
(Parent or Guardian's Signature)

Signed: _____________________________ Date: ____________
(Student’s Signature)

Signed: _____________________________ Date: ____________
(Researcher’s Signature)
Dear Parent/Guardian:

Your child is invited to participate in a research study. Dr. Christopher Andersen, an Assistant Professor at The Ohio State University, and Nejla Yuruk, a doctoral student at The Ohio State University, will be conducting this study. The purpose of this study is to compare the effectiveness of two different teaching approaches on students’ learning of science and to better understand how children learn science. Your child’s physics teacher and a doctoral student from The Ohio State University are working together to design the teaching activities.

In order for the researchers to conduct the study, one of the researchers, Nejla Yuruk, will be in your child’s classroom for 9 weeks. During this time, the researcher will observe and may talk to the students. Your child will be asked to be involved in learning activities that are being used by your child’s physics teacher as part of his regular classroom practices. Your child’s involvement in the learning activities does not require additional time from your child. Tests which assess students’ learning of science will be administered three times during the study. Completing of each test may take 50 minutes or less. Classroom instruction will be videotaped. Video-recordings will be used to remember the events and activities of the classroom as a whole; the learning of individual students on the videotapes will not be studied. All the videotapes will be stored at a secured location only accessible to the researchers and will be destroyed upon the completion of the study.

Your child can benefit from this study. The learning activities that will be used may help your child see the real world applications of scientific principles. There is no known or foreseeable risk that might be expected from your child’s participation in this study.

Your child’s participation is entirely voluntary. Your child’s grade will not be affected by his/her decision to participate or not to participate in this study. The results of this study will not be used to evaluate your child’s behavior or performance. Your child’s grade will be determined by your child’s physics teacher based on homework, quizzes or exams. The researchers will not be involved in giving a grade your child. Your child may withdraw any time without consequences of any kind. Should your child decide to withdraw, his/her data will be destroyed without penalty or loss of benefits as a student.
All the information collected from this study will remain confidential and will be used only for the purpose of the research. We plan to share the results of the study through publication in academic journals and presentation at conferences. No reference will be made in written and oral reports that could be linked to your child or to the school. The names of persons and places may be changed; pseudonyms will be used for all names of persons and places.

If you have questions about your child’s rights as a participant of this study, please contact The Office of Responsible Research Practices, Third Floor, Research Foundation Building, 1960 Kenny Road, Columbus, Ohio 43210-1063; Phone: 688-8457

We explained the purpose of this study and described what your child’s participation in the study might require. If you are willing to grant permission, and if your child is willing to participate, please sign the consent form attached to this letter and ask your child to return it to his/her physics teacher as soon as possible. It is necessary that both you and your child sign the form in the spaces indicated. Keep this letter for your records.

You may have questions or concerns during the time of your child’s participation in this study, or after its completion. If you have any questions regarding this study, please feel free to contact the researchers Dr. Christopher Andersen or Nejla Yuruk at the addresses and phone numbers provided below.

Sincerely,

Nejla Yuruk
657 Tuscarawas Ct.
Columbus OH 43210
Phone: (614) 688-9126
e-mail: yuruk.1@osu.edu;

Christopher Andersen
Founders 2048
1179 University Drive
Newark OH 43055
Phone: (740) 366-9304
e-mail andersen.18@osu.edu.
CONSENT FOR PARTICIPATION IN SOCIAL AND BEHAVIORAL RESEARCH

Protocol Title: The Effectiveness of Metaconceptual Teaching Practices on Students’ Conceptual Understanding and Their Views of Learning

Protocol Number: 2003B0218

Researchers: Dr. Christopher Andersen (Principal Investigator)
Nejla Yuruk (Co-Investigator)

I consent to my participation in (or my child’s participation in) research being conducted by Christopher Andersen and Nejla Yuruk of The Ohio State University.

I have read and understand the information in the attached letter regarding the purpose of the study, the procedures that will be followed, and the amount of time it will take. I understand the possible benefits, if any, of my participation (and/or my child’s participation). No guarantees have been made regarding the effectiveness of the learning activities that will be used in this study.

I know that I can (and/or my child can) choose not to participate without penalty. If I agree to participate, I can (and/or my child can) withdraw from the study at any time, and there will be no penalty.

I consent to the use of videotapes. I understand how the tapes will be used for this study.

I have had a chance to ask questions and to obtain answers to my questions. I can contact the investigators at andersen.18@osu.edu, (740) 366-9304; or yuruk.1@osu.edu, (614) 688-9126. If I have questions about my rights as a research participant, I can call the Office of Research Risks Protection at (614) 688-8457.

I understand in signing this form that, beyond giving consent, I am not waiving any legal rights that I might otherwise have. My signature on this form does not release the investigator, the sponsor, the institution, or its agents from any legal liability for damages that they might otherwise have.

I have read this form or I have had it read to me. I sign it freely and voluntarily. A copy has been given to me.

Print the Name of the Participant

______________________________
Signed: _____________________________ Date: ____________
(Parent or Guardian's Signature)

______________________________
Signed: _____________________________ Date: ____________
(Student’s Signature)

______________________________
Signed: _____________________________ Date: ____________
(Researcher’s Signature)
Dear Parent/Guardian:

We are writing to request your permission for your child to participation in interviews that will be conducted as part of a research study carried out by Dr. Christopher Andersen, an Assistant Professor at The Ohio State University, and Nejla Yuruk, a doctoral student at The Ohio State University. The purpose of conducting the interviews is to clarify your child’s science concepts and ideas about learning science. We will ask questions about some physics concepts that will be learned in class and views about learning science. Information collected from these interviews will help us understand the thinking processes of students as they learn science.

If you agree to grant permission and if your child agrees to participate in the interviews, your child will be asked to meet with Nejla Yuruk individually 2-4 times for 40 minutes or less over two months. These interviews will not cause your child to miss out on regular classroom instruction. The interviews will be conducted at school at times convenient to your child’s schedule.

With your consent, the interviews will be audio-taped and photocopies of your child’s drawings will be made. The purpose of audio-taping is to help the researcher stay focused on the conversation and it will ensure that the researcher will have an accurate record of what your child would say during the interviews. The audio-tapes and your child’s drawings will be kept in a secure location only accessible to the researchers and will be destroyed after the research is completed.

All the information collected from this study will remain confidential and will be used only for the purpose of the research. Information collected during the interviews will not be made available to your child’s school administration or used by your child’s physics teacher to evaluate the performance of your child when assigning grades.

When we share the results of the study through publication in academic journals and presentation at academic conferences no reference will be made in written and oral reports that could be linked to your child or to the school. The names of persons and places will be changed; pseudonyms will be used for all names of persons and places.

There is no known or foreseeable risk that might be expected from your child’s participation in the interviews. Your child’s participation in the interviews is entirely voluntary. Your child’s grade will not be affected by his/her decision to participate or not to participate in the interviews. Your child may withdraw any time without consequences of any kind. Should your child decide to withdraw, his/her data will be destroyed without penalty or loss of benefits as a student.
If you are willing to grant permission, and if your child is willing to participate, please sign the consent form attached to this letter and ask your child to return it to his/her physics teacher as soon as possible. It is necessary that both you and your child sign the form in the spaces indicated. Keep this letter for your records.

If you have questions about your child’s rights as a participant of the study, please contact The Office of Responsible Research Practices, Third Floor, Research Foundation Building, 1960 Kenny Road, Columbus, Ohio 43210-1063; Phone: 688-8457

If you have any questions regarding this study, please feel free to contact the researchers Dr. Christopher Andersen or Nejla Yuruk at the addresses and phone numbers provided below.

Sincerely,

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e-mail andersen.18@osu.edu.
CONSENT FOR PARTICIPATION IN SOCIAL AND BEHAVIORAL RESEARCH

Protocol Title: The Effectiveness of Metaconceptual Teaching Practices on Students’ Conceptual Understanding and Their Views of Learning

Protocol Number: 2003B0218

I consent to my participation in (or my child’s participation in) the interviews being conducted by Christopher Andersen and Nejla Yuruk of The Ohio State University.

I have read and understand the information in the attached letter regarding the purpose of the interviews, the procedures that will be followed, and the amount of time it will take.

I know that I can (and/or my child can) choose not to participate in the interviews without penalty. If I agree to participate, I can (and/or my child can) withdraw from the study at any time, and there will be no penalty.

I consent to the use of audiotapes and my (and/or my child’s) drawings. I understand how the tapes and my child’s drawings will be used for this study.

I have had a chance to ask questions and to obtain answers to my questions. I can contact the investigators at andersen.18@osu.edu, (740) 366-9304; or yuruk.1@osu.edu, (614) 688-9126. If I have questions about my rights as a research participant, I can call the Office of Research Risks Protection at (614) 688-8457.

I understand in signing this form that, beyond giving consent, I am not waiving any legal rights that I might otherwise have. My signature on this form does not release the investigator, the sponsor, the institution, or its agents from any legal liability for damages that they might otherwise have.

I have read this form or I have had it read to me. I sign it freely and voluntarily. A copy has been given to me.

Print the Name of the Participant

________________________________________
Signed: _____________________________  Date: ____________
(Parent or Guardian’s Signature)

________________________________________
Signed: _____________________________  Date: ____________
(Student’s Signature)

________________________________________
Signed: _____________________________  Date: ____________
(Researcher’s Signature)
APPENDIX B

INTERVIEW PROTOCOLS
Interview Protocol-Part I (Students’ Ideas About Force and Motion)

Instructions

I appreciate your letting me ask a few questions. This interview consists of two sets of questions. The overall objective of the first set of questions is to gain insight into your conceptual understanding of some physics concepts. I will either ask the questions verbally or I will show you a picture of a situation and ask questions about the given situation. I’d like you to THINK ALOUD as you work on the questions you will be given. What I mean by think aloud is that I want you to tell me EVERYTHING you are thinking from the time that you first see or hear the questions until you give me an answer. I would like you to talk aloud CONSTANTLY from the time you begin working on a question until you have a response. I may ask you additional questions for further clarification about your responses. As you know, I am not native speaker of English. If you do not understand what I ask you, it will not offend me in any way. You may ask me to repeat the question or you may ask clarification if you do not understand the question. You may also read the written form of the questions. You may draw pictures, lines or arrows if you think they are helpful in answering the questions.

The objective of second set of questions is to understand what you think about learning science concepts. I will ask you a few questions regarding your experience in learning science.

Your responses will be recorded on a tape and I will make a copy of your drawings. It will help me stay focused on our conversation and it will ensure that I have an accurate record of what we discussed. All information you provide will be kept
confidential and will not be used for any purposes other than this study. You privacy will be completely protected.

**Interview Questions**

1. What does the word force mean to you? What kinds of characteristics could you list to describe it? What words do you associate with this concept? How do you know that force is acting on an object? Do you think that it is possible to sort things as either exerting force or not exerting force? Can you give some examples of things that exert force? Can you give some examples of things that don’t exert force? Can you give some examples of things that cannot ever exert force? What kinds of things can exert force?

2. You see a book sitting on the table (A book was placed on the table by the researcher). Are there any forces acting on this book? How many in what directions do they act? Explain where these forces come from.

**Probing Questions:**

- If you think that the book exerts force on the table, why isn’t the book moving?
- Do you think the table exerts force on the book? If so, how?
Could you compare the amount of force exerted by the book on the table and the force exerted by the table on the book?

3. I push this book across the table with my finger so that it moves from this point (let’s call it point A) to this point on the table (let’s call it point B) [A book sitting on the table was pushed by the researcher]. What are the forces acting on the book while it moves from point A to point B?

Probing Questions:

- Why does it stop after a while?
- If the only force acting on the book is the friction that is exerted against the motion of the book, then how does the book move?
- What should I do to keep the book moving at a constant speed?
- When I push the book with my finger, does the book exert any force on my finger? Could you compare the amount of the force I exert on the book to push it and the force exerted by the book on my finger?
- What is the least amount of the force I need to exert on the book to make it move on the table?
- Suppose that I push this book on a very smooth surface where there is no friction. Could you describe how its motion would be? What forces would be acting on the book along its movement? Would it be speeding up, slowing down or moving at a constant speed?

4. I put this ball on the edge of the table and push it with my finger so that it drops to the ground. Could you describe the path of the ball after it goes over the edge of
the table? What are the forces acting on the ball as it moves off the edge of the table to the ground?

Probing Questions:

- What could you say about the amount of the forces acting on the ball as the ball is falling?
- Does the amount of the forces acting on the ball increase, decrease or stay constant as the ball is falling?

5. Could you describe what happens when I throw this ball as it travels up and then back to my hand in terms of its speed and the forces acting on this ball? [A ping-pong ball was tossed up by the researcher].

Probing questions:

- Could you describe what happens as it rises? Does it speed up, slow down, or move with a constant speed? Are there any forces acting on the ball as it rises? Could you compare the amount of the forces acting on the ball with the throw-up force (the force I exerted on the ball to throw it up)?
- What happens at the peak? Are there any forces acting on the ball at the peak?
- What happens when it is falling down to the ground? What are the forces acting on the ball? Does it speed up, slow down, or move with a constant speed?
- How strong are the forces acting on the ball compared to each other?
• What could you say about the amount of the gravitational force acting on the ball as it moves? Does it decrease, increase, or stay constant as the ball goes up and falls down?

• Suppose that I toss the same ball the space where there are no near planets or other outside forces. What would happen to the ball? What would you say about the motion of the ball? What would you say about the speed of the ball? What would be the forces acting on the ball?

6. Suppose that I have a light and a heavy ball of the same size and shape in my hand, a ping-pong ball and a metal ball. Suppose that I drop both of the balls from the same height at the same time. Which one would hit the ground first and why? Explain your reasons.

Probing Questions:
• Could you compare the amount of force acting on each ball?
• If you think that the amount of force acting on the balls of the force acting on both balls is not the same, does this mean that they accelerate at the same rate?
• What if I drop two objects of the same mass but different shapes, such as a Frisbee and a plastic ball with the same weight? Would your answer change? What would be the forces acting on them?

7. A large truck breaks down out on the road and receives a push back into town by a small compact car as shown in the figure below. As the car pushes the truck, the truck’s speed increases. Does the car exert any force on the truck? Does the truck exert any force on the car? Explain your reasons.
Probing Questions:

- If both the car and the truck exert force on each other, could you compare the amount of forces exerted by the car on the truck and the amount of the force exerted by the truck on the car?
- How does the truck move forward if it pushes the car backward?
- Why doesn’t the car move to the left if the truck pushes the car back?
- After awhile, the car has pushed the truck enough that they have reached a constant cruising speed. Do you have an idea about the amount of the force the car exerts on the truck so that the truck moves with at constant speed?
- Suppose that the car and the truck are on an icy road. What would happen if the car pushes the truck? Do the car and the truck exert any force on each other? Could you describe their movement? Would they speed up, slow down, or stop?

8. This diagram shows a frictionless semicircular metal tube with the center at point “O.” In the diagram, you are looking down on the tube from above, and the tube is lying flat on a table. A moving metal ball enters the tube at “p” and exits at “r.” Force exerted by the air is negligible. Are there any forces acting on the ball when
it is within the tube at point “q”? What path would the ball follow after it exits the tube? Explain your reasons.

Probing Questions:

- Are there any forces acting on the ball after it exits the metal tube?

*Additional Questions Asked in the Post-Interview*

If there is a difference between the responses of the students in the pre-interview and post-interview students were reminded of their previous response and they were asked why they changed their minds.
Interview Protocol-Part II (Ideas About Concept Learning)

Interview Questions

1. Have you ever had a science idea that is different from what you read in your textbook or what your science teacher explains? In other words, do you sometimes have different explanations for the things happening in the natural world?
   i. (If, yes) How do you think those ideas of your own influence your learning of science?
   ii. What is the advantage of learning the scientific explanation over using your own ideas to explain the things happening in the natural world?

2. When you encounter a particularly difficult idea to learn, what do you do?
   i. How do you begin to understand the ideas that are not your own?
   ii. How do you know the new idea is better than your own idea?
   iii. What happens to your old idea after you accept a new idea?
   iv. How do you know you learned the new idea?

3. I want you to think about your learning experiences in the last 5 weeks, specifically your learning experiences of Newton’s Laws.
   i. Was this course taught different from other science courses you took before?
   ii. Was your learning in this course different from other courses before?
4. Suppose that you encounter two different ideas about the things happening in the natural world. For example, a friend of yours in the class thinks that there cannot be a force without motion. Another friend of yours has a different idea. He believes that forces may act on an object that is not moving. How do you decide that one idea can explain the situation better than the other?

5. You’ve been telling me a lot of different things about how people learn science. Can you tell me in one big summary about what you know about how people learn science.
APPENDIX C

GROUP-BASED METACONCEPTUAL TEACHING ACTIVITIES

AND

JOURNAL PROMPTS
Activity-1 (Poster Drawing-Group Activity)

WHAT DO WE KNOW ABOUT FORCE?

Instructions
A. Work as a group to explain to each other what you know about the word force. Your ideas may involve:
   ➢ Definition of force;
   ➢ Attributes which you may use to describe force;
   ➢ Words you may associate with the word force;
   ➢ The kinds of the effects force produces on objects;
   ➢ Things that can or cannot exert force (if it is possible to make such a classification);
   ➢ Kinds of forces you may think of;
   ➢ Three real life examples in which forces are acting on objects.

   Be sure to explain to each other your reasons behind your ideas.

B. Then, as a group draw a poster that represents your group’s ideas about force.

C. Present your poster to class. During your presentation, explain how your group members’ ideas about force were different when you were discussing your ideas.

Note: Before you start discussing your ideas, make sure that the tape-recorder is working in the PLAY/RECORD mode. Record the name of each group member and the title of the activity (“poster drawing, what do we know about force”).
Activity-2 (Journal Writing/Group Discussion)
MY INITIAL IDEAS ABOUT FORCE(S)
ACTING ON A HORIZONTALLY MOVING OBJECT

Instructions
A. Within your group, slide an object (a book, a box, or a ball) across a smooth surface. Try to slide the object by applying a constant push for a while along a distance (from point A to B).

Think about the following questions by yourself before discussing them with your group. Then, write a brief summary of your ideas in your journal. Explain your reasons behind your ideas.

From Point A to B
➢ What is/are the force(s), if any, acting on the object on its way from point A to B?
➢ Do you have an idea about the amount of the force(s) acting on the object?
➢ What is the direction of the force(s) acting on the object?
➢ Describe the motion of the object from point A to B? Does it speed up, slow down, or move at a constant speed? Why?
➢ Is there any relationship between the force(s) acting on the object on its way from point A to B and its motion?

B. At point B give the object a strong push so that it moves for a while and stops at point C.

Think about the following questions by yourself before discussing them with your group. Then, write a brief summary of your ideas in your journal. Explain your reasons behind your ideas.

From point B to C
➢ What is/are the force(s), if any, acting on the object on its way from point B to C?
➢ What is the direction of the force(s) acting on the object?
➢ What must be the least amount of force that needs to be exerted on the object to make it move?
➢ Describe the motion of the object from point B to C? Does it speed up, slow down, or move at a constant speed? Why?
➢ Is there any relationship between the force(s) acting on the object on its way from point A to B and its motion?
C. Discuss your ideas and your reasons behind your ideas with other classmates in your group. Be prepared to summarize your group's ideas to the class.

Note: Before you start discussing your ideas as a group, make sure that the tape-recorder is working in the PLAY/RECORD mode. Record the name of the each group member and the title of the activity ("my initial ideas about force acting on a horizontally moving object").
Activity-3 (Journal Writing/Pair Debate)

My Initial Ideas about Forces

Acting on a Horizontally Moving Object in the Absence of Friction

Instructions

➢ Suppose that you give an object (a ball, a book or a box) a strong push on a very smooth frictionless surface. Which of the alternatives below represents your idea about the horizontal force, if any, acting on the object along its travel on the frictionless surface:

   A. There is no horizontal force acting on the object.
   B. There is force acting on the object in the direction of its motion.

Think about the motion of the object. Do you think it will speed up, gradually slow down or move at a constant speed?

In your journal,

• write a paragraph about why the alternative you chose is the best answer for the given question.
• briefly describe how the motion of the object would be?
• compare the forces, if any, acting on an object that is moving on frictionless surface and on a surface with friction.
• explain the reasoning behind your ideas.

➢ Group with classmates who chose a different alternative for the question above. Explain to your group why the alternative you chose is the best answer for the question and how the motion of the object would be after it is pushed. Discuss with your group how the forces, if any, acting on the object on frictionless surface and on surface with friction differ. Defend your ideas by explaining the reasoning behind your ideas.

Note: Before you start discussing your ideas with your partner, make sure that the tape-recorder is working in the PLAY/RECORD mode. Record your name and name of your partner, and the title of the activity (my initial ideas about force acting on a horizontally moving object in the absence of friction).
Activity-4 (Journal Writing/Group Discussion)
MY INITIAL IDEAS ABOUT GRAVITY

Instructions
A. Think about the following questions by yourself before discussing them with your group. Then, write a brief summary of your ideas in your journal. Explain your reasons behind your ideas.

- What does gravity mean to you?
- What do you understand from the statement “constant gravity”?
- What is the difference between mass and weight?

B. Discuss your ideas and your reasons behind your ideas with other classmates in your group. Be prepared to summarize your group’s ideas to the class.

Note: Before you start discussing your ideas as a group, make sure that the tape-recorder is working in the PLAY/RECORD mode. Record the name of the each group member and the title of the activity (“my initial ideas about gravity”).
Activity-5 (Journal Writing/Group Discussion)
BOOK ON THE TABLE

Instructions

A. Place a book on the surface of your table. Think about the force(s), if any, acting on the book as it rests on the table.

The arrows in the pictures below show the direction and the amount of the forces acting on the book. Which of the pictures below do you think best shows the force(s), if any, acting on the book as it rests on the table?

In your journal, write why the alternative you chose is the best answer for the given question. Explain the reasoning behind your ideas.

B. You will be asked to work as a group with classmates who chose different pictures to describe the force(s), if any, acting on the book. Explain to each other why the picture you chose is the best answer for the question. Defend your ideas by explaining your reasoning behind your ideas. Notice any differences among the ideas of the group members.

Note: Before you start discussing your ideas as a group, make sure that the tape-recorder is working in the PLAY/RECORD mode. Record the names of the group members, and the title of the activity ("book on the table").
Activity-6 (Journal Writing/Group Discussion)

Forces That Resist Horizontal Motion

Instructions

A. As a group, try to push an object (a box, a book, wood block) horizontally across the floor. Start with a gentle push and increase your push gradually until you can move the object with constant speed.

Think about the following questions by yourself before discussing them with your group. Then, write a brief summary of your ideas in your journal. Explain your reasons behind your ideas.

- Explain briefly what you experienced when you tried to push the object at first.
- Determine the forces acting on the object while you try to push the object and while it moves at a constant speed.
- What is the least amount of force needed to start the object in motion? How is the force needed to start the object's motion related to the weight of the object?
- What is the amount of the force needed to keep the object moving at constant speed? How is the force needed to keep the object moving at a constant speed related to the weight of the object?
- Is there any difference between the amount of force needed to start object's motion and to keep it moving at a constant speed?

D. Discuss your ideas and your reasons behind your ideas with other classmates in your group. Be prepared to summarize your group's ideas to the class.

E. Make measurements to determine the force you apply to start the object in motion and to keep the object moving at constant speed.

- Measure the weight of the object by using a spring balance.
- Place the object on the floor and pull it parallel to the surface with the spring balance to achieve a motion at constant speed.
- Record the force you apply to start the object in motion and the force you apply to keep the object moving at constant speed.
- Compare the weight of the object with the force you applied to start the object in motion and to keep the object moving at constant speed.
- Notice any differences, if any, between what you initially thought and what you observed.
- Discuss with your group members the differences in your initial ideas and what you observed.

**Note:** Before you start discussing your ideas as a group, make sure that the tape-recorder is working in the PLAY/RECORD mode. Record the name of the each group member and the title of the activity ("forces that resist horizontal motion").
Activity-7 (Journal Writing/Group Discussion)

THROW A BALL UP

Instructions

A.

- Throw a ball (or another object) straight up into the air so that it leaves your hand, goes up and falls down again.
- The arrows in the pictures below show the direction and the amount of the forces acting on the ball. Which of the pictures below do you think best shows the force(s), if any, acting on the ball while it is rising? Think also about the force(s), if any, acting on the ball at the peak of its trajectory and while it is descending.
- In your journal, write why the alternative you chose is the best answer for the given question. Explain also the force(s) acting on the ball at the peak of its trajectory and while it is descending. Explain the reasoning behind your ideas.

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B. You will be asked to work as a group with classmates who chose different pictures to describe the force(s), if any, acting on the ball.

- Explain to each other why the picture you chose is the best answer for the question.
- Explain to each other the force(s), if any, acting on the ball at the peak of its trajectory and while it is descending.
Defend your ideas by explaining your reasoning behind your ideas. Notice any differences among the ideas of the group members.

**Note:** Before you start discussing your ideas as a group, make sure that the tape-recorder is working in the PLAY/RECORD mode. Record the names of the group members, and the title of the activity ("throw a ball up").
Activity-8 (Journal Writing/Group Discussion)

MY INITIAL IDEAS ABOUT 2-DIMENSIONAL MOTION

Two different situations are provided below. For each situation, think about the following questions by yourself before discussing them with your group. Then, write a brief summary of your ideas in your journal. Explain your reasons behind your ideas.

A. A bullet is shot horizontally with an initial velocity.

- What is the path the bullet follows after it is shot? Why do think the bullet follows the particular path you describe? Can you think of other situations in which an object follows a similar path?
- What are the forces, if any, acting on the bullet as it falls? What is the direction of the force(s), if any, acting on the bullet?
- How does the velocity of the bullet changes as it falls to the ground?
- What would the bullet's path look like it is shot with the same initial velocity on the moon? Compare the path of the bullet that is shot on the Earth and on the moon?

B. A student jumps up on the bus as it travels along the road.

- What is the path of the student as observed by a classmate on the bus?? Why do you think the student follows the particular path you describe? Can you think of other situations in which an object follows a similar path? Is the path of the student different from the path of the bullet in the previous question? If yes, why?
- What are the forces acting on the student after she leaves the floor of the bus?
- How does the velocity of the student change as she travels?
- What would the student’s path on Earth look like if the force applied to jump is increased or decreased? Compare the path of the student who jumps with high and low initial velocity?
- What would the student’s path look like if she jumps with the same initial velocity on the moon? Compare the path of the student on the Earth and on the moon?
- Suppose that gravity switch could be "turned off" at various points such that the student would travel in the absence of gravity.
What would the motion of the student be like if the gravity switch is turned off:

1. At the point when the student leaves the floor of the bus?
2. At the peak of the student’s trajectory?
3. While the student is falling?

C. Discuss your ideas and your reasons behind your ideas with other classmates in your group. Be prepared to summarize your group’s ideas to the class.

Note: Before you start discussing your ideas as a group, make sure that the tape-recorder is working in the PLAY/RECORD mode. Record the names of the group members, and the title of the activity (“initial ideas about 2-dimensional motion”).
Activity-9 (Concept Mapping/Relational Diagram)

Instructions

- Arrange the following terms into a map or diagram so that the map or the diagram represents the relationships between the terms. Draw the map or diagram in to your journal book.

  - Force
  - At rest
  - Motion
  - $F_{net} < 0$
  - No Force
  - Acceleration
  - Balanced Forces
  - Unbalanced Forces
  - $F_{net} = 0$
  - $F_{net} > 0$
  - Constant speed
  - Deceleration
  - (Other terms you may think of)

- Provide examples from your everyday life for each situation in your diagram.
- After you draw the diagram, explain to your group your diagram and the examples you provided. Are there any differences between your diagram and your classmate's diagram?

Note: Before you start explaining your diagram, make sure that the tape-recorder is working in the PLAY/RECORD mode. Record your name and your partner's name and the title of the activity ("concept mapping").
Activity-10 Skateboard Activity (Journal Writing-Group Discussion)

A. Four different situations are provided below. For each situation, think about the following questions by yourself before discussing them with your group.

- What are the forces, if any, acting on the persons and objects (student A, student B, student C, student D, wall, shopping cart...). Describe the direction of the forces? Why do you think the forces act in the particular direction you specify?
- For each situation, compare the amount of the forces acting on the persons or objects. Which forces cancel each other?
- Describe the motion (if any) of the persons and objects in each situation? Specify the direction of the movement. Why do you think objects or persons move in that particular direction?

For each situation, write a brief summary of your ideas about the above questions in your journal. Explain your reasons behind your ideas.

1. A student standing on a skateboard pushes on the wall.

2. Students A (65 kg) and student B (65 kg) are standing on identical skateboards. Student A gently pushes student B.

3. Students C (90 kg) and student D (65 kg) are standing on identical skateboards. Student C gently pushes student D.

4. A person pushes a shopping cart so that they move at a constant speed.

B. Discuss your ideas and your reasons behind your ideas with other classmates in your group. Be prepared to summarize your group’s ideas to the class.

C. Demonstrations

- For the 1st, 2nd and 3rd situations, predict the direction of the movement.
For the 1st situation (student standing on the skateboard pushes on the wall), observe the demonstration. Notice the direction of the movement.

For the 2nd and 3rd situations (student standing on skateboard pushes another student), observe the demonstrations. How do the students move after one student pushes the other? For each situation, compare the distance traveled by each student.

For the 4th situation (a person pushes a shopping cart), observe what happens when a student standing on the floor and another student standing on a skateboard are trying to push a wheeled chair. Notice the direction of the movement of the student and wheeled chair in each situation.

D. Discuss with your group the following issues:

- Discuss your observations for each situation? For each situation, are your observations consistent with what you predicted? Does what you observed support or refute your initial arguments?
- What do all demonstrations have in common?
- How does 2nd situation differ from the 3rd situation? For each situation, what would you say about the amount of the forces acting on the students? How far did each student travel compared to the other in each situation? Why?
- What happened when a student standing on the floor and another student standing on a skateboard pushed a wheeled chair? Provide a theoretical explanation for what you observed? What are the forces acting on the students and on the wheeled chair in each situation?
- Be prepared to summarize your group’s ideas to the class.

Note: Before you start discussing your ideas as a group, make sure that the tape-recorder is working in the PLAY/RECORD mode. Record the name of each group member and the title of the activity (“skateboard activity”).
Activity-11 Circular Motion (Journal Writing/Group Discussion)

Instructions

A. Suppose that an object (e.g. a ball, a can or a stopper) attached to a string is being twirled by someone in a horizontal circle on a frictionless surface at a constant speed.

➢ What are the forces, if any, acting on the object as it travels in a circle? In what direction do the forces, if any, act on the object?
➢ Is the object accelerating as it travels in a circle at a constant speed?
➢ While twirling the string, the person releases the string from his hand. In what direction does the object go after the string is released? Why? What are the forces, if any, acting on the object after the string is released from the hand of the person?

Think about the questions above by yourself before you discuss them with your group. Then, write a brief summary of your ideas in your journal. Draw the path followed by the object after the string is released. Explain what makes you to have your ideas about the given situation.

B. Discuss your ideas and your reasons behind your ideas with other classmates in your group. Be prepared to summarize your group’s ideas to the class.

C. Observe the demonstration about an object moving in a circle. Notice the direction of the object’s motion after the string attached to it is released.

D. Discuss with your group the following issues:

➢ Are your observations consistent with what you initially predicted?
➢ Provide a theoretical explanation for what you observed.
➢ Be prepared to summarize your group’s ideas to the class.

Note: Before you start discussing your ideas as a group, make sure that the tape-recorder is working in the PLAY/RECORD mode. Record the name of the each group member and the title of the activity ("circular motion").
Activity-12 Poster Drawing / Group Discussion

REVISITING POSTERS ABOUT FORCE

As a group, look at the poster your group produced to describe your group’s initial understanding of force. Discuss the following:

➢ Is there anything you would like to add to or delete from your poster?
➢ Is there anything you would like to change in your poster?
➢ Why would you like to make those changes or additions?

You may draw another poster if you think it is necessary. Be prepared to present the additions or the changes you made in your posters to the class. During your presentation, explain and justify why you made those changes.

Note: Before you start discussing, make sure that the tape-recorder is working in the PLAY/RECORD mode. Record the name of each group member and the title of the activity ("revisiting posters about force").
JOURNAL PROMPTS

Journal #1 (given after activity 1)

As a group, you discussed your understanding of force and prepared a poster that depicts what you already know about force. During this group project, did anyone in your group have ideas that were different from yours? Give examples. When you had different ideas about force how did you decide on the idea you put on your poster?

Journal #2 (given after activity 2)

As a group and class, you discussed the forces acting on an object that moves horizontally as a result of applying a constant push for a while (from point A to B) and after a strong push (from point B to C).

➢ During the group and class discussions, were there any differences between your ideas and other classmates’ ideas about the motion of the object and forces acting on the object?
➢ Beside your own idea was any other idea attractive to you? Why?
➢ Have you noticed any limitations of your ideas to explain the given situation?
➢ Can you think of any situation where your initial ideas or other classmates’ ideas about the relationship between force and motion do not work?

Journal #3 (given after activity 3)

With your partner, you discussed the force acting on an object that moves horizontally along a frictionless surface.

➢ Did you understand your partner’s reasons behind his/her ideas?
➢ In what ways were your partner’s ideas different from yours?
➢ Are your partner’s ideas believable to you? Why/ Why not?
➢ Have you changed your mind about the alternative you chose for the question about the forces acting on an object that moves on a frictionless surface? Why did/didn’t you change your mind?

Journal #4 (given after class discussion about Newton’s First Law)

➢ Do you understand Newton’s First Law? How do you know you understand it?
➢ Is there anything that is not believable to you in Newton’s First Law? Why?
➢ In what ways is your initial understanding about the relationship between force and motion different from what is presented in Newton’s First Law?
➢ Can you think of situation(s) that can be better explained by Newton’s First Law than by your initial ideas? In what ways can Newton’s First Law provide a better explanation?
After a class discussion about Newton’s First Law, have you noticed any changes in your ideas about the forces acting on objects and their motion? If there are changes in your ideas, what made you change your ideas?

Journal #5 (given after class discussion about Newton’s First Law)

Newton’s First Law (Law of Inertia) states that objects resist changes in their state of motion unless acted upon by unbalanced forces. Like objects, sometimes our ideas resist changes too. Draw an analogy between inertia of our ideas about natural world and inertia of objects. By using this analogy (“inertia of ideas”), explain what kinds of things you would consider as balanced forces and unbalanced forces.

Journal #6 (given after activity 4)

As a group and class you discussed your ideas about gravity and differentiate between weight and mass.
- Do you understand why everything falls to the Earth at the same rate? How do you know you understand it? Could you explain it to someone else by your own words?
- In what ways were your initial ideas about the falling rate of heavy and light objects different from what you observed in class?
- Do you understand the difference between gravitational acceleration and gravitational force? Were you able to differentiate between gravitational force and gravitational acceleration before the group and class discussions? Which concept were you referring to when you were using the word “gravity”?
- Do you understand the difference between weight and mass? Did you know the difference between mass and weight before the group and class discussions?
- Are there any changes in your ideas about gravity, mass and weight? In what ways are your current ideas different from what you initially thought?

Journal #7 (given after activity 5)

As a group and class you discussed your ideas about the forces acting on a book as it rests on a table.
- What was your initial idea about the force(s) acting on the book?
- Do you understand the reasoning behind why the table exerts an upward force on the book? How do you know you understand it?
- Is the idea of an upward force exerted by the table on the book different from what you initially believed?
- Is the idea that an inanimate, solid, inactive object like a table can exert force believable to you? In other words, does this idea fit in with your other ideas you know or believe, or is it the way you see things work? Why / Why not?
Have you changed your mind about the alternative you have chosen for the question about the forces acting on the book? If yes, why do you think your current idea is better than your initial idea? What made you change your initial idea? If no, why do you think the alternative you chose is the best answer for the given question?

Journal #8 (given after activity 7)

As a group and class you discussed your ideas about the forces acting on the ball which is thrown up.

- What were your initial ideas about the forces acting on the ball while it rises up, while it is at the peak of its trajectory and while it falls? Why do you think you hold those initial ideas?
- While discussing your ideas about the forces acting on the ball as a group or as a class, did you notice any differences between your ideas and other classmates’ ideas? Was any idea that was different from your initial idea attractive to you? Why/Why not?
- Did you initially think that there is an upward force acting on the ball from the moment it leaves the hand of the person? If yes, what kinds of attributes did you assign to the force concept? Are the attributes that you assigned to the force concept different from scientists’ conceptualization of the force concept?
- Some of your classmates hold the idea that the only force acting on the ball is the gravitational force even though the ball moves in the upward direction as it rises up. Some others think that there must be an upward force which is greater than the gravitational force as the ball rises up because the ball is moving in the upward direction. Which idea is more attractive to you? Why are you against the other idea? Are there situations in which the direction of the force acting on the object is the same with the direction of the motion? Can you think of other situations in which the direction of the force acting on the object is different from the direction of its motion?
- Have you changed your mind about the alternative you have chosen for the question about the forces acting on the ball which is thrown up? If yes, why do you think your current idea is better than your initial idea? What made you change your initial idea? If no, why do you think the alternative you chose is the best answer for the given question?

Journal #9 (given after activity 8)

As a group and class you discussed your ideas about the forces acting on a bullet shot horizontally off a cliff and on a student who jumped up on a bus.

For the bullet shot horizontally off the cliff:

- What were your initial ideas about the forces acting on the bullet as it falls to the ground and the path followed by the bullet? What was your reasoning behind your ideas?
Some of your classmates hold the idea that the bullet follows a parabolic path for a while until gravitational force overcomes the bullet’s inertia, and then it moves in a straight line until it reaches the ground. Some others think that the bullet follows a complete curved (parabolic) path (no straight line motion) until it hits the ground. Which idea is more attractive to you? Why are you against the other idea?

Have you changed any of your initial ideas regarding the forces acting on the bullet and the motion of it? If yes, why do you think your current ideas are better than your initial ideas?

For the student who jumps up on the bus:

What were your initial ideas about the forces acting on the student after she/he leaves the floor and the path followed by the student differ from the path followed by the bullet? Why?

Which of the Newton’s ideas do you apply to this situation?

Have you changed any of your initial ideas regarding the forces acting on the student and the motion of her/him? In case you changed your ideas why do you think your current ideas are better than your initial ideas?

Journal #10 (given after activity 9)

You discussed your initial ideas about the forces acting on persons and objects for the given 4 situations in the “skateboard activity.” Why do you think you hold your initial ideas? What was your reasoning behind your ideas?

Have you noticed any limitations about your initial ideas during the group discussions and demonstrations?

Were any results of the demonstrations different from what you initially predicted?

Which situation was the hardest for you to provide an explanation or to understand other’s explanation? Why?

Did you experience any difficulties in understanding the Newton’s Third Law?

Can you apply Newton’s Third Law to situations other than provided in the “skateboard activity” sheet?

Have you changed your mind about the forces acting on the persons and objects provided in the skateboard activity sheet? If yes, what made you change your initial idea?
Journal-11 Forces Acting on Objects in Different Situations (Fill in the Table/Journal Writing
Instructions
A. A list of objects in different situations is provided below. For each situation, explain what your initial ideas were about the forces acting on the object. You may look at your previous journal entries to remember your initial ideas. The situations provided below may not be identical with those in your journals; however, there are similarities among the situations (e.g., a ball at rest on the floor or a book at rest on the table (Activity 5)). Then, explain your current ideas about the forces acting on the objects in each situation. Notice the differences between your initial and current ideas.

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<td>1. A ball at rest on the floor.</td>
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<tr>
<td>2. A ball rolling on the floor, slowing down.</td>
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<tr>
<td>3. A hockey puck sliding on frictionless ice,</td>
<td></td>
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<td>with a constant speed.</td>
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<tr>
<td>4. A ball rolling on the floor, speeding up.</td>
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<tr>
<td>5. A hockey puck sliding on frictionless ice,</td>
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<tr>
<td>speeding up.</td>
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<td>6.</td>
<td>A ball rolling on the floor, with constant speed.</td>
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<tr>
<td>7.</td>
<td>A box moving down the inclined plane, speeding up.</td>
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<tr>
<td>8.</td>
<td>A box stays at rest on the inclined plane.</td>
<td></td>
</tr>
<tr>
<td>9.</td>
<td>A box moving up the inclined plane, at constant speed.</td>
<td></td>
</tr>
<tr>
<td>10.</td>
<td>A ball tossed straight up, while ball is rising.</td>
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<tr>
<td>11.</td>
<td>A ball tossed straight up, ball at the top of its trajectory.</td>
<td></td>
</tr>
<tr>
<td>12.</td>
<td>A ball tossed straight up, while ball is descending.</td>
<td></td>
</tr>
<tr>
<td>13.</td>
<td>A parachute moving down with constant velocity.</td>
<td></td>
</tr>
</tbody>
</table>
14. A balloon rising, speeding up.

15. A balloon rising with constant speed.

16. A basketball shot by a basketball player towards the hoop, as it is rising up.

B. Write in your journal about the following issues:

- Examine the consistency of your ideas about the forces acting on objects and the relationship between force and motion of objects across different situations. Group similar situations (in a way that makes sense to you) and compare the consistency of among your initial and current ideas within each group. Are your ideas consistent among similar situations?

- Discuss the applicability and generalizability of scientific laws (Newton’s Laws) and your own ideas across different contexts (situations). Why do you think it is important to learn scientific principles?