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A Case Study of One Student's Metaconceptual Processes and the Changes in Her Alternative Conceptions of Force and Motion

Nejla Yürük
Gazi Üniversitesi, Ankara, TURKEY

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The aim of this paper was to describe the changes in one student's ideas about force and one-dimensional motion concepts and portray the relevant metaconceptual processes that she engaged in during the implementation of metaconceptual teaching interventions. Metaconceptual processes involves metacognitive processes that are directly acting on or related to individuals' conceptions, mental models or elements of their conceptual ecology. Several types of instructional activities including poster drawing, concept mapping, group debate, journal writing and group and class discussions were used to activate students' metaconceptual processes. The findings of the study indicated that the student changed all of her alternative ideas that were assessed before the instruction with scientifically accepted conceptions following the instruction. The findings also showed that the student engaged in several types of metaconceptual processes ranging from simple awareness of ideas to more sophisticated metaconceptual processes, such as metaconceptual monitoring and evaluation. The findings strengthen the claims about the positive impact of metaconceptual processes on changing students' conceptions of physical world.

Keywords: Conceptual Change, Metacognition, Metaconceptual Processes

INTRODUCTION

In recent years, the importance of metacognitive processes in facilitating the change in students' existing conceptions has been acknowledged by many researchers (Georghiades, 2004; Vosniadou, 2003). In this research metaconceptual teaching interventions that aimed to activate a group of students' metaconceptual processes were implemented. This paper presents the changes in a single student's conceptions of force and motion and describes the metaconceptual processes that she engaged in during her involvement in metaconceptual teaching practices.

Correspondence to: Nejla Yürük, PhD,
Gazi Üniversitesi, İlköğretim Bölümü, Fen Bilgisi Öğretmenliği Anabilim Dalı, Teknikokullar
06500, Ankara, Turkey
E-mail: nejlayuruk@gazi.edu.tr

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Theoretical Framework

This research rests on two main bodies of literature: conceptual change and metacognition.

Conceptual Change Process

Studies conducted in the field of science teaching and learning clearly demonstrated that students come into classrooms with existing ideas that are different from those accepted by the scientific community and these alternative explanations exist even after formal instruction (Driver & Easley, 1978). Existence and resistance 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). This view of learning attracted the interest of

researchers to search for theoretical models to explain the nature of the change process, and develop instructional approaches to promote the change in students' conceptions. .

The Conceptual Change Model proposed by Posner et al. (1982) has been one of the popular theoretical frameworks in science education for several years. This model described the conditions that need to be satisfied for an individual to change his/her ideas, and the components of individual's conceptual ecology. Research studies conducted in the area of cognitive psychology have also proposed theoretical frameworks about the nature of the change in students' conceptions (Vosniadou, 1999). In the mid-1990s many researchers proposed theoretical explanations for what changes in the conceptual change process (Chi, Slotta & Leeuw, 1994; diSessa, 1993; Ueno, 1993; Vosniadou, 1994). According to these researchers, learners' ontological (Chi et al., 1994) and epistemological presuppositions (Vosniadou, 1994), their "self-explanatory" everyday experiences (diSessa, 1993) and the context (Ueno, 1993) plays a significant role in the development of alternative conceptions. For them, in order to experience a change in alternative conceptions learners should compare and contrast their existing conception and new ideas, recognize, integrate and evaluate existing and new conceptions and associated commitments, everyday experiences and contextual factors. These processes assume a learner who is aware of his/her conceptual system, monitors the consistency between his/her existing ideas and information coming from different sources and evaluates the new and existing ideas by providing justifications. Awareness, monitoring and evaluation are the subcomponents of metacognition. Pintrich and Sinatra (2003) stated that the theoretical models proposed to explain the change in students' conceptions make an "assumption about the importance of metacognitive awareness" (p. 432). Several researchers acknowledged the role of learners' metacognitive processes in changing their conceptions (Beeth, 1998; Ferrari & Elik, 2003; Georghiades, 2004; Hennessey, 1999, 2003; Vosniadou, 1994, 2003; White & Gunstone, 1989).

Metacognition and Metaconceptual Processes

Metacognition is a very broad construct that has gained a great deal of attention in cognitive and educational psychology. Although it has been extensively studied metacognition has been described as a "fuzzy concept" (Flavell, 1981, p. 37). It is broadly defined as "one's knowledge and control of own cognitive system" (Brown, 1987, p. 66). It is also described as one's "inner awareness" about one's learning process, what one knows or one's current cognitive state (Hennessey, 2003) and "knowledge about knowledge. Kuhn, Amsel and O'Loughlin (1988) defined metacognition as "thinking explicitly about a theory one holds (rather than only thinking with it)" (p.7). As these definitions suggest, metacognition subsumes three main types of knowledge and processes: (a) one's acquired knowledge about cognition, (b) online awareness of one's stock of information and (c) control and regulation of one's cognitive processes.

Various kinds of knowledge and processes have been identified as metacognitive in their nature. Researchers identified knowledge and processes, such as knowledge about problem solving or reading strategies, 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 as metacognitive (see Brown, 1978; Flavell, 1979; Garner, 1987; Hacker, 1998; Schraw & Moshman, 1995). These knowledge and processes play a role in successfully performing a cognitive task (Hennessey, 2003). However, these domain general knowledge and processes may not bring about a major restructuring in learners' conceptual systems. As the theoretical frameworks proposed to explain the change in students' conceptions suggest, achieving a major restructuring requires metacognitive knowledge and processes that are acting on or related to learners' conceptual system. Since the term metacognition subsumes several types of knowledge and processes it is fruitful to differentiate metacognitive knowledge and processes that are acting on and related to one's conceptual system from other metacognitive knowledge and processes. I use the term "metaconceptual" to refer to metacognitive knowledge and processes that are acting on and related to one's conceptual system. Recently, an increasing number of researchers started to use the term "metaconceptual" to refer to the meta-level thinking processes that are acting on students' conceptions (see, for example, Mason & Boscolo, 2000; Vosniadou, 1994, 2002, 2003; Wiser & Amin, 2001)

Based on the theoretical distinctions among the subcategories of metacognition which are an acquired knowledge about one's cognition, online 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 major components: (a) metaconceptual knowledge, (b) metaconceptual awareness, (c) metaconceptual monitoring and (d) metaconceptual evaluation.

Metaconceptual knowledge refers to one's acquired stable and statable knowledge about concept learning and the factors affecting one's concept development. Metaconceptual awareness is one's online awareness of and reflection on existing concepts and elements of conceptual ecology including one's interpretation of experiences, ontological and epistemological presuppositions. Metaconceptual monitoring involves

control processes which generate information about one's cognitive state and thinking processes. Metaconceptual evaluation involves processes in which learners make judgmental decisions about the relative ability of the competing conceptions to explain the real phenomenon. Both metaconceptual monitoring and metaconceptual evaluation processes occur during the learners' attempts to learn a conception. Examples to these processes are monitoring the comprehension of conceptions, the consistency between the existing and new conception, the changes in ideas and making comments about the relative plausibility, usefulness and validity of existing and new ideas.

Purpose of the Study

Metaconceptual processes require learners to engage in abstract and higher levels of thinking which is not easy to achieve through formal instruction. In this study, metaconceptual teaching activities were implemented to facilitate students' engagement in the above stated metaconceptual processes. The aim of this case study is to describe the changes in one student's understanding regarding force and one-dimensional motion concepts and portray her metaconceptual activities that she engaged in during the metaconceptual teaching activities. In this paper, I did not intend to prove or disprove the effectiveness of metaconceptual teaching activities, but rather I portrayed a case of metaconceptual processes that took place during the implementation of the metaconceptual teaching interventions and the relevant changes in the conceptions of the student. In that sense, this case study is descriptive and explanatory rather than confirmative.

Case studies are very useful in terms of gaining a deep insight into the learning processes of one student. Case studies are descriptive and inductive in the sense that a researcher may seek to understand a larger phenomenon through close examination of a specific case. Although the metaconceptual teaching interventions covered variety of topics related to force and motion, such as Newton's First Law, Newton's Second Law, Newton's Third Law, friction, projectile motion, gravity, and circular motion, the target case student's ideas and metaconceptual processes were examined within three main topics: definition of force, relationship between force and motion, and Newton's First Law of Motion.

Within the limits of this article, it is not possible to describe every metaconceptual process that the student displayed regarding to every conceptual topics covered by the activities. However, the examples given for these three main topics are representative enough to show the diversity of her metaconceptual processes and the changes in the relevant conceptions.

METHODS AND PROCEDURES

Design of the Study

The metaconceptual teaching activities were implemented in a physics classroom of a high school located in Ohio, in the USA, There were 22 eleventh and twelfth grade students in the class and most of them had not taken a physics course in the past. The student for the case study was chosen so as to span a range of alternative ideas about force and motion and to have the ability to communicate his/her ideas well during the implementation of the study. In doing so, it was aimed to portray metaconceptual processes with content involving a wide range of alternative ideas that changed throughout the instructional interventions. The student was identified by observing students for two months before the instruction related to Newton's Laws started and by examining students' pre-instructional scores on the Force Concept Inventory (FCI). FCI is a systematically developed multiple-choice test designed by Hestenes, Wells and Swackhamer 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). Within the science education community, it is one of the widely used diagnostic tools in existence for assessing students' conceptual understanding of Newtonian mechanics (Hake, 1998; Henderson, 2002).

Data Sources

The changes in the case student's ideas regarding force and motion concepts and her metaconceptual processes relevant to those ideas were examined by collecting data from multiple sources before, during and following the instructional interventions. The data regarding the case student's metaconceptual processes were derived from the 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), and journal writings. One-to-one semi-structured interviews were conducted prior to and after the instruction to assess her alternative ideas, areas of confusion, and the gaps in her understanding of force and motion concepts. One of the open-ended questions aimed at exploring how the student defined force and what characteristics she attributed to this concept. The other interview questions involved showing her a series of situations in the forms of pictures, demonstrations, or verbal explanations. She was 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 were similar to the questions in the FCI (Hestenes, Wells & Swackhamer, 1992). An example for the questions asked during the interviews is provided below:

Example:

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?
- 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?

Metaconceptual Teaching Practices

In order to facilitate students' engagement in metaconceptual knowledge and processes several types of instructional activities including poster drawing, concept mapping, group debate, group and class discussion and journal writing were employed. At various points throughout the instructional interventions, these instructional activities were blended with demonstrations or hands-on experiments so as they served as domain specific metaconceptual prompts in the form of making predictions and providing explanations about a given situation, comparing and contrasting predictions with what is observed, evaluating existing ideas in relation to the observed data. Laboratory experiments about friction, Newton's Second Law and projectile motion were used without any explicit attempt to facilitate metaconceptual processes.

Poster Drawing. Through poster drawing activity it was aimed to facilitate students' engagement in metaconceptual awareness and metaconceptual monitoring. At the beginning of the instructional interventions, in order to encourage students to become metaconceptually aware of their existing ideas, experiences and relevant presuppositions they were prompted to produce posters about their group's understanding of force concept along with examples from their daily experiences. In order to facilitate students' engagement in monitoring the consistency between their initial understanding and current ideas about force concept, the poster drawn by the students were given back to them near the end of instructional interventions. Students were asked to think about the changes they wanted to make in their initial posters and explain why they want to make those changes. Students were asked to present their initial and final posters to their classmates.

Journal Writing. Journal writing provided students with the opportunity to engage in several types of metaconceptual processes. The journal prompts given to the students encouraged them to step back and reflect on their existing conceptions, examine the reasons why they were attracted to their existing views or information coming from different sources, monitor their understanding and the differences in different views to explain a physical phenomenon, make judgments on the validity of different ideas about a topic under investigation, recognize the limitations of their views, look for consistency among their ideas across different contexts, and monitor the changes in their ideas. Students were also requested to write about their learning of science concepts. For example, they were asked to write about how and under what conditions they change their ideas by drawing upon an analogy between Newton's First Law and changes in their science ideas or to compare the applicability and generalizability of scientific principles and their own ideas.

Examples for the journal prompts given to the students are provided below.

> "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?"
>
> "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?"
>
> "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 among your initial and current ideas within each group. Are your ideas consistent

among similar situations? [As part of this journal prompt, students were given a table in which they were asked to write their initial and current ideas abut forces acting on objects in different situations]."

Group Debate. Group debate activity was employed to help students become aware of their ideas and associated presuppositions about a physical phenomenon, justify their ideas, and evaluate the validity of different views as they discuss their ideas with other students who hold different ideas. Students were asked a conceptual question with multiple alternatives and they were requested to choose one among the several alternatives. Students who chose different responses were asked to explain each other why the alternative they chose was the best explanation for the physical phenomenon presented in the question.

Group and Classroom Discussions. The purpose of using classroom or group discussion activities was to bring diversity of opinions held by the member of the class about a physical phenomenon and their ideas about their learning of science concepts into open. Students were facilitated to describe explicitly their own ideas, the reasons behind their ideas and to compare and contrast among different ideas. Students in groups of three or four were asked to discuss their ideas about a given situation or before performing a demonstration or hands-on experiment. After the group discussion, students summarized what they discussed as a group. The teacher did not introduce the scientific explanation until the students couldn't provide further explanation for the physical phenomenon Examples of the discussion prompts used by the teacher 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?" "Why do you think so?" "Is it [their observations] different from what you initially thought?" "Do you agree with your group's idea?" "Do you understand what your friend just said?" Students were also prompted to discuss how they learn concepts, why their ideas are different, why is it important to reflect on what they already know, the difference between understanding and believing, and how they know they understand a concept.

Concept Mapping. Concept mapping activity aimed to help students see the relationships among different concepts. Students were provided with a number of terms, such as "$F_{net}=0$," "$F_{net}<0$," "$F_{net}>0$", "constant speed," "at rest," "motion," "acceleration," and "deceleration." They were asked to arrange the terms into a map so that the map represented the relationships between the terms. After they produced the diagrams they summarized their concept maps to other students in their groups.

DATA ANALISYS AND FINDINGS

This section portrays the ideas that Lisa held prior to and following the instructional interventions about force and one-dimensional motion and describe her metaconceptual processes that she engaged in as she participated in metaconceptual teaching practices.

Lisa's Case

Lisa is an eleventh grade student who 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 a case 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 25 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, 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 kind of motion (R denotes Researcher):

R: How do you know that force is acting on an object?
Lisa: Previous experience.
R: 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.
R: All of your examples involve motion. Do you associate force with any kind of motion?
Lisa: Any motion.
R: What about constant motion?
Lisa: Yes.

The excerpt taken 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 having no forces acted upon produced constant speed.

Throughout the interview she 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.

R: Is there a way to keep it moving at a constant speed?
Lisa: No. Because you have two forces acting on it.
R: 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.
R: Okay. What should I do to keep the book moving at a constant speed?
Lisa: Take away friction?
R: 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.

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. In situations where there were no opposing forces, she held the idea that the objects moved at a constant speed due to a force acquired from the agent to the objects. 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.

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

Another alternative idea that Lisa possessed was her belief that the force in the direction of the object's motion had to be greater than the force in the opposite direction even though the object was moving at a constant speed. 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.

R: 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.
R: What do you mean by overcomes?
Lisa: The force of the car must be more than the force of friction because they are moving.

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. 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.

R: 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 draw pictures if you would like to [The researcher pushes a book on a table and let the book slide across the table].
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 gravity is always pulling down on it.
R: Could you draw a figure showing the forces?[Lisa draws a figure that shows an arrow in the direction of book's motion].
R: Okay, does the force that I used to push the object from point A to point B still act on the book as it moves from point A to point B?
Lisa: Yes, because the book is moving.
R: 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 and. did not change but rather stayed constant as the object moved.

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.

R: 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.
R: Will it slow down or increase its speed eventually?
Lisa: No, not unless it come in contact with another force.
R: 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.
R: 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.
R: Is it still exerting on the book while it's on a frictionless surface?
Lisa: Yes, it's exerting force.
R: Does it increase, decrease, or stay constant while it moves?
Lisa: Stays constant.
R: Why do you think it stays constant?
Lisa: Because there is no force acting against your push.

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.

R: 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.
R: 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 her, 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.

R: What should I do to keep the book moving at a constant speed?
Lisa: You have to take away friction.
R: 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.

R: What would happen if one of the forces is greater that the other one?
Lisa: Then the book would move.
R: 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. 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.

R: 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 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 A to B the only force acting on the book is friction.
R: 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.
R: What would you say about the speed of the book as it moves from point A to B?
Lisa: The speed is decreasing.
R: Why is it decreasing?

Lisa: Because the friction is accelerating, in this case it is decelerating it.
R: 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.
R: 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 normal force, she thought that the only force acting on the book in the opposite direction of its motion was friction.

In contrast to her response that there was an acquired force acting on a ball moving in the upward direction 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.

R: 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.

With the aim of further clarification of her idea of inertia, Lisa was asked whether inertia was an entity that was comparable to gravity.

R: 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 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. 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 acting 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.

R: 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 the force is applied it will continue at a constant speed.
R: Does it stop eventually or does it float around?
Lisa: No it just keeps going until it is acted upon by another force.
R: 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.

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

Throughout the instructional interventions, Lisa changed all of her alternative ideas that were identified 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 1. A drastic change is seen in her idea that objects acquire force 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, she successfully acquired the scientific view of inertia. For her, there was no longer a need for 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. 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 not only stated that force caused objects to accelerate, but she was also able to differentiate the outcome of

Table 1. Lisa's pre-instructional and post-instructional ideas about force and one-dimensional motion.

Pre-instructional Ideas	Post-instructional Ideas
• Force creates any kinds of motion. • No differentiation of the outcome of balanced and unbalanced forces. • The amount of the force in the direction of the object's motion must be greater than that of the opposing force. • The act of setting objects in motion imparts in them a force. • Force acquired by objects after they are set in motion keeps them moving. Therefore, moving is not considered as a natural state of objects. • Force acquired by an object acts in the direction of object's movement and stays constant throughout object's travel. • Objects cannot move at constant speed if two forces in opposite directions act on the object.	• Force is a push or a pull. • Force causes objects to accelerate. • 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. • 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. 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.

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.

The data from the pre- and post-instructional interviews indicate that Lisa acquired a better scientific understanding after the instructional interventions. She changed all of her alternative ideas that were identified 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.

Overview of the Types of Metaconceptual Processes

To better understand the metaconceptual processes that Lisa engaged in, it is necessary to provide a brief description of the qualitatively different metaconceptual processes derived from the analysis of the transcripts. There are three main types of metaconceptual processes found in the data: (a) metaconceptual awareness, (b) metaconceptual monitoring, and (c) metaconceptual evaluation. During the data analysis, after assigning the student's statements to these general types of metaconceptual processes, subcategories were developed by comparing one incident to another. The data was gone over for several times to find segments that exemplified the list of metaconceptual processes in the coding scheme. Below is the description of the general types of metaconceptual processes and subcategories appeared in each one of them.

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 awareness and second-order metaconceptual awareness.

A. *First-Order Awareness:* First-order 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 awareness, they may also refer to a conceptual entity that is missing in their existing conceptual structure. Within the category of first-order awareness, five subcategories were derived from the data.

   1) *First-Order 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.

2) *First-Order 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.
3) *First-Order Awareness of What You Do Not Know: 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
4) *First-Order 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).
5) *First-Order Awareness of Experiences:* Learners make reference to a particular experience when they engage in first-order awareness of past experiences.

B. *Second-Order Metaconceptual Awareness:* 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 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.
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.
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.
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.
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.

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 in relation to a new information. 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.
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 or information coming from other sources.
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.
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.
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.

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.
2) choosing an idea among different alternatives and defending why that idea works better than the other ones for the given situation.

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. As Lisa participated in various metaconceptual teaching activities, she engaged in several types of metaconceptual processes. 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 Law and relative amount of forces to move an object. 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.

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.

During the poster drawing activity, Lisa became aware of her understanding of force. 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 awareness of her ideas about force by making an explicit definition of it. She 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 describeforce.
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, activity1)

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 awareness of her idea). During the class discussion, which took place after group discussion about a book moving as it was constantly pushed by the teacher's finger from point A to B, Lisa explicitly restated her idea that force caused objects to move. Below is the excerpt taken from the class discussion (T denotes Teacher).

T: 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.
T: What would they be? So what relationships are there between forces and motion?
Lisa: Forces create motion. (Excerpt from class discussion after activity 2)

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 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.

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 differentiae acceleration as the outcome of force from other kinds of motion ("Yeah, interaction that can cause acceleration."). She 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…").

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. She 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 awareness of this idea in a journal entry related to activity 2. 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 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 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 constant overcoming friction.") (First-order awareness of her idea). Also 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 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, Lisa displayed evidence for another type of metaconceptual awareness. In journal prompt, 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 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. In that sense her metaconceptual evaluation process was not sophisticated.

When students were asked to make a journal entry in which they group similar situations (different situations were provided in a table along with a journal prompt) and examine the consistency of their initial and current ideas for different situations, 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 (object moving at constant speed vs. increasing speed). In doing so, she engaged in second-order awareness of contextual differences.

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.").

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. 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 a group discussion activity. In this activity, students were requested to identify forces acting on a moving book after it was set in motion by a strong push. Below is the excerpt taken from Lisa's journal entry?

> 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 awareness of her existing ideas. ("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.

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. 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 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 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 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."). In doing so, she engaged in first-order awareness of what she did not know. 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 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. 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 then my partners 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. 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 used them."). 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. 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. 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."). 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 awareness of her ontological presuppositions. Lisa was able to make a similar distinction in her journal entry written in response to journal prompt given after activity 7. 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 one of her journal entry.
> 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.").

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

Throughout the instructional activities related to force and one-dimensional motion, 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 show Lisa's engagement in the first-order 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.

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, she 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 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 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.

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.

DISCUSSION, CONCLUSION and IMPLICATIONS

In this paper, one student's science ideas that she had prior to and after the metaconceptual teaching interventions were examined and the changes in her ideas were summarized. Then, her metaconceptual processes about those ideas were portrayed. In describing the student's metaconceptual processes, they were examined by using taxonomy of metaconceptual processes derived from the analysis of the collected data. The findings of the study indicate that all of the student's alternative ideas identified prior to the instruction changed with the scientifically accepted conceptions following the metaconceptual teaching practices. The findings also showed that this student engaged in several types of metaconceptual processes ranging from simple awareness of her ideas to more sophisticated metaconceptual processes, such as monitoring and evaluation of ideas.

The findings of this exploratory case study should be interpreted carefully. Although the observed changes in the student's science ideas and the relevant metaconceptual processes 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 collected data due to the multifaceted and multidimensional character of metaconceptual processes. To date, the nature of the mechanisms of this relationship has not been fully identified. An isolation of a single type of metaconceptual process and investigating the effect of that process on the changes in science ideas would not be possible as some processes already involves one's engagement in other metaconceptual processes or a single metaconceptual process may invoke one's engagement in others. For example, monitoring changes in ideas requires a learner to engage in first-order awareness of current ideas and second-order awareness of initial ideas and make a comparison between initial and current ideas.

Any theoretical and/or empirical attempt to investigate the nature and mechanisms of how a particular type of metaconceptual process influences and brings about change in students' ideas would be a great addition to our understanding of concept learning. It is clear that both conceptual change and metaconceptual processes are complex and occur through the interaction of several constructs. In this study, the observed changes in the student's ideas should not be treated as the single cause of the observed

metaconceptual processes but rather they are the product of the interaction of metaconceptual and cognitive processes as well as social and motivational factors. Therefore, the observed metaconceptual processes should be considered as a contributor to the restructuring in the participant's conceptual system.

Keeping in mind that making an attempt to show a particular type of metaconceptual process as the cause of the changes in students' ideas can be only partially successful; it would not be inappropriate to state that the participant of this case study became aware her existing alternative ideas, mental models and relevant ontological presuppositions, consciously compared and contrasted existing ideas with information coming from different sources, monitored the changes in her ideas and evaluated the validity of ideas by providing justifications. The findings indicate that this student who engaged in these domain specific metaconceptual processes was able to realize the limitations of her idea, construct new ones that were more plausible and fruitful to her and recognize the phenomenon that she did not know or understand. Her realization of the missing elements of her conceptual ecology enhanced her interest to understand the unknown conceptual entities. It is obvious that all of these processes have potential to contribute to the acquisition of conceptions that were accepted with the science community. Examination of the participant's responses to interview questions provides an evidence for the extent of the changes in her ideas of force and one-dimensional motion. Her responses indicate that the changes in her ideas not only were at the factual level but her ideas also changed at the ontological level implying not a surface level but a major restructuring in her conceptual structure about force and motion. It would not be inappropriate to claim that the ontological changes in her ideas should be closely related to her metaconceptual awareness of the ontological distinctions between inertia and force concept which was activated through metaconceptual teaching interventions. Wiser and Amin's study (2001) also reported the positive effect of metaconceptual teaching that addresses the fact that students and scientists may use the same terms for different conceptual entities on conceptual understanding of heat and temperature.

This study not only gives signs of the positive short-term impact of facilitating metaconceptual processes but also long-term a potential positive impact on students' conceptual understanding Students' regression to their initial alternative ideas short time after the instruction is an important problem in science learning (Georghiades, 2001). Monitoring the changes in ideas is a metaconceptual process that may potentially play a significant role in maintaining the durability of learners' current ideas because one's monitoring of the changes in ideas has the capability to generate information about the validity of initial and current ideas. During the post-interview, the student in this study displayed evidence for the coexistence of her initial and current ideas about forces and for her acquisition of knowledge about the validity of their initial and current ideas:

R: 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…
R: Do you still use your initial idea?
Lisa: For inertia?
R: 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 ofinertia sometimes?
Lisa: Yes.
R: 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 that 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. Acquiring information about the validity of previous and current ideas would become available to learners when they remember their initial ideas. As long as students retain this kind of information in their memory, the restructuring in learners' conceptual understanding would be more permanent. Her scores on the FCI administered nine weeks after the metaconceptual teaching interventions reflect the durability of her scientifically acceptable ideas. Out of the 30 items she could answer 27 item following the instruction and 25 items nine week after the instruction correctly. This finding indicates that even nine weeks after the instruction Lisa retained most of her scientifically accepted conceptions that she constructed

throughout the metaconceptual teaching interventions. The long-term impact of facilitating metaconceptual processes on students' conceptual understanding was also reported in Blank's (2000) and Georghiades's (2004) studies.

The findings show that the participant of this case study engaged in a variety of metaconceptual processes ranging from simple awareness of her ideas to more sophisticated higher-order thought processes. The level of sophistication at which the 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. These findings indicate that metaconceptual thought is not a "all or none" phenomenon, but rather these processes are in the repertoire of learning behaviors of students, the content, the frequency, or the level of their sophistication of them may vary from one context to another, and they can be activated when structured opportunities were provided for the students.

This study strengthens the claims of introducing instructional activities that facilitate students' engagement in metaconceptual processes into classroom settings. The teaching-learning environment created in this study was different from traditional instruction in which students sit passively, listen to the teacher, and memorize facts about the physical world. When appropriately facilitated students' have the ability to become aware of their conceptual structure, monitor their concept learning and evaluate ideas coming from different sources. Metaconceptual thought should not be disregarded at the expense of the loaded science content but rather it should be an integral part of the curriculum.

It should be kept in mind that the conclusions drawn from this study are limited only to a single student observed for this case study. Investigating students' metaconceptual processes in other subject areas within different age levels may potentially produce scientific knowledge about students' abilities to engage in metaconceptual processes and the interaction of the metaconceptual processes with the subject matter. Further research that investigates the metaconceptual processes of multiples cases would enable us to grasp a more complete picture of the nature of higher order thinking that are acting on learners' conceptual systems and its contribution to the concept learning.

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