AN INVESTIGATION OF THE CONCEPTUAL CHANGE PROCESS OF BEGINNING COLLEGE LEVEL PHYSICS STUDENTS STUDYING NEWTON'S LAWS

by

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Under the Direction of Mary Atwater

ABSTRACT

Students who successfully undergo conceptual change utilize certain cognitive strategies to accomplish conceptual change. Conceptual change has two components: capture depending upon the intelligibility, plausibility, and fruitfulness of a new concept to a student. And, exchange which requires dissatisfaction with an existing concept prior to the acceptance for a suitable replacement. The literature also lists awareness, evaluation, regulation and reflection as variables associated with conceptual change. Taken as a whole, these components help students to develop strategies for conceptual change. This investigation utilized constructivist theory as its theoretical framework and employed the case study approach to explore and describe the processes of conceptual change undertaken by students studying Newton's Laws in a beginning college physics course. The specific research questions were as follows:

(1) What are the strategies used by students who are successful in undergoing conceptual change when studying Newton's Laws?

(2) What are the strategies used by students who are not successful in undergoing conceptual change when studying Newton's Laws?

(3) What is the relationship between the kind, complexity and difficulty of the concepts in an experiment and the resulting conceptual change?

The researcher utilized the Force Concept Inventory (FCI) as the pre test to assess the student participant's understanding of concepts associated with Newton's Laws and identified the two concepts that were least understood on the basis of the test. The researcher then randomly selected two groups of five students, each assigned to study one of the two misconceptions.

The first misconception was associated with a question that asked the students to identify the forces acting on the hockey puck through its trajectory. Of this group, only three of the five participants underwent conceptual change. Upon reviewing the conceptual change strategies, two of the participants utilized awareness, evaluation and regulation, and reflection. Only two participants utilized all four characteristics of dissatisfaction, intelligibility, plausibility, and fruitfulness.

The second misconception was related to an elevator moving upward in an elevator shaft at constant speed. Only one participant utilized all four conceptual change strategies: awareness, evaluation, regulation and reflection. He used only three of the four characteristics associated with the Conceptual Change Model: intelligibility, plausibility, and fruitfulness.

Explanations for these findings are rooted in constructivist theory in which conceptual change occurred when the understanding of key concepts formed the foundation for the construction of subsequent key concepts.

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CHAPTER 1 - INTRODUCTION

Background and Significance

In 1957, the United States entered a race for scientific supremacy when Russia launched a space probe into outer space. This single event marked the start of the U.S./USSR space race, ushering in new technological and scientific developments and challenges. Colleges and universities in the United States responded to the challenge by seeking to improve problem-solving and critical thinking, hoping to boost scientific literacy through education reform. These reform initiatives sought to translate K-12 education by replacing fact-based instruction with a process-driven curriculum and to supplement textbooks that stressed content with scientific inquiry and mathematical problem solving (Bybee, 1997).

One might pose the following question to institutions of higher education: "What changes in policies and practices will be necessary to support K-12 reforms that promote science literacy in higher education? How should undergraduate education build on science literacy goals devised for K-12 education?"

Science for All Americans (SFAA, 1989) suggested that many U.S. colleges and universities had begun the task of producing scientifically literate graduates. However, certain barriers existed in these institutions, which interfered with the development of scientific literacy among students. Goroff (1995) suggests that many teacher education programs endorse the notion that "how we teach is what we teach," suggesting that instructional methods used by instructors are often, in turn, used by these students as professional educators. Further, many university faculty members adhere to standards of clarity in teaching rather than focusing on the process of teaching, thereby prompting student teachers to unknowingly adopt these same ineffective instructional methods (American Association for the Advancement of Science, 1998). Thus, the “just be clear” philosophy in teaching is a barrier to scientific literacy that fails to consider the human aspects of teaching, resulting in “watered-down” science courses (American Association for the Advancement of Science, 1998).

The institutional culture observed at many research-oriented universities reveals the existence of an instructional “pecking order” which serves as a barrier to scientific literacy, in which younger, active and less experienced faculty members, along with older, formerly active researchers teach undergraduate courses. Further, many professors consider science courses for non-majors as less favorable and less rigorous, often devoting less time and effort teaching these courses (American Association for the Advancement of Science, 1998). This self-fulfilling prophecy acts as another barrier to achieving scientific literacy within higher education, resulting in poorly prepared science and non-science majors with distorted conceptions of science.

Another barrier among many U.S. universities is the physical separation between science faculty and science education faculty, which effectively limits opportunities for K-12 teachers to learn more about the practice of science. In addition, this segregation minimizes the exposure of scientists to K-12 curriculum and the understanding among scientists of the misconceptions and prior knowledge that incoming freshmen bring into the classroom (American Association for the Advancement of Science, 1998).

If achieving scientific literacy for all Americans is to be realized, university professors will need to embrace the idea that allowing students to construct their own knowledge is more beneficial than exposing them to the traditional methods of instruction. Hence, accepting scientific inquiry, which lends itself well to knowledge construction (constructivism), is a first step in the process. Further, achieving scientific literacy among university students requires the instructor to assume a role of facilitator in leading the student to the accepted conceptions, rather than attempting to indoctrinate the student. Finally, university professors, who are not normally concerned with prior knowledge, must consider the conceptions brought into the classroom by students and the impact that these conceptions have on future learning.

According to the National Science Education Standards (1996), scientific literacy begins with the need for a broad basis of knowledge. The scientifically literate individual should be able to read and understand science information, identify science-related issues and reasonably predict the outcome of natural phenomena. A literate individual should be able to evaluate the quality of scientific information and assess any arguments presented on the basis of evidence. Finally, the scientifically literate person must be able to formulate conclusions. Therefore, becoming scientifically literate requires building a strong framework of complete, accurate and scientifically acceptable knowledge skills required to understand, identify, predict and evaluate issues related to science.

Scientific literacy in higher education has evolved as a related set of attitudes directed toward developing skills in life-long learning, problem-solving and decision-making (NCES, 1996a). Daily learning experiences and prior knowledge imported from diverse backgrounds present instances for pre-college students to explore, analyze, evaluate, synthesize, appreciate, and understand the interrelationships among science, technology and society. Further, opportunities for inquiry demonstrate ways that science and the environment will affect their personal lives, their careers, and their future. Thus, integrating inquiry and student experiences is a central strategy for teaching science (NCES, 1996a).

Different members of society view scientific literacy differently. As a physics professor, my view of scientific literacy compares strongly to that of the previous description in that students who complete a beginning physics course should possess the conceptual arsenal required to assess, evaluate and articulate their scientific views. However, because my teaching emphasis is domain-specific, my perspective of scientific literacy stresses the ability to synthesize ideas related to Classical Mechanics rather than simply developing inert knowledge. Thus, a physics professor likely believes that a broad and deep basis of knowledge in Classical Mechanics, Electricity & Magnetism and Modern Physics coupled with the ability to make informed decisions with this knowledge constitutes specific scientific literacy. Alternatively, scientific literacy among those charged with managing educational enterprises likely adopt a more global perspective of scientific literacy by focusing on the need and ability of graduates to utilize technology to benefit society.

The word *physics* comes from a Greek word meaning "knowledge of nature" (Jones & Childers, 1999). Physics attempts to explain and to describe the fundamental nature of our universe and the underlying mechanics of it. Physics is the science of nature, the study of natural objects and the forces acting upon it (hyperdictionary.com, 2003b). Physics investigates the causes and effects of gravitation, heat, light, and magnetism.

Undergraduate physics instruction is typically subdivided into three segments. One segment focuses on the laws governed by velocities approaching the speed of light

(Relativity). Another segment studies the descriptions of matter at the atomic level (Quantum Mechanics). A third segment emphasizes laws associated with ordinary-sized objects (Classical Mechanics).

Physics I, typically referred to as Introduction to [Classical] Mechanics, begins with a study of measurements, vector analysis and kinematics. "Measurements" introduces students to the "language of science." Students study the Metric System and methods for converting quantities used in the U.S. to the Metric System equivalents. Vector Analysis demonstrates methods for "drawing" quantities (vector quantities), such as forces, velocities, accelerations, and displacements, for analysis. Kinematics, the study of motion, enables students to analyze motion utilizing mathematical models. These topics help to prepare students for an in depth study of Newton's Laws, which sets the foundation for the remainder of classical mechanics. Mastery of classical mechanics in turn, provides the necessary conceptual foundation for students studying engineering, physics, and technology. A weak conceptual framework in Newton's Laws and Classical Mechanics will result in a scientifically illiterate and inadequately prepared technical professional.

As constructivist theory suggest, the basis of learning lies in the construction of new knowledge atop prior knowledge. Consider the metaphor of building a structure on a foundation. A strong foundation results in a strong and enduring structure; a weak foundation does not adequately support the structure and thus the structure fails. The same is true for learning. Strong conceptual foundations enable the learner to build broad, deep and strong conceptual frameworks. Misconceptions arise from a loosely defined conceptual framework that presents opportunities to incorporate incorrect information (Meyer, 1993). Consequently, a sound conceptual foundation provides the "footing" necessary for the construction of new knowledge. Further, the correctness of existing conceptions on which to build new knowledge coupled to incoming knowledge creates the conditions necessary for the construction of new knowledge that is vital for the occurrence of deep learning.

Though educators espouse the notion that conceptual understanding is a critical component of deep and significant learning (Entwistle & Perry, 1974), conventional instruction in higher education is ineffective in promoting the deep comprehension required to master Classical Mechanics (Gow & Kember, 1990; Halloun & Hestenes, 1985). Further, the teacher-centered perspective of instruction does little to promote improved learning or conceptual understanding. This perspective portrays the teacher as one who "writes" information on the "tablet" of the student's mind by transmitting knowledge "down" to the student (McDermott, 1983). In reality, teachers present fully formulated and generalized conceptions to their students without any active engagement or knowledge construction on the part of the student (McDermott, 1983). This lack of student engagement in the process of knowledge construction frustrates the construction of scientifically acceptable conceptions.

Statement of the Problem

According to Hestenes and Halloun (1985a), naive learners (non-Newtonian thinkers) enter into instruction with an existing and well-defined knowledge base derived from their everyday experiences. These non-Newtonian thinkers have yet to achieve an acceptable level of understanding of Newtonian mechanics (Hestenes & Halloun, 1995).

Theorists characterize non-Newtonian thinkers as (a) maintaining undifferentiated concepts of velocity and acceleration; lacking a vectorial concept of velocity, (b) lacking a universal force concept, i.e., believing that there are other influences on motion besides forces, and unable to reliably identify the agents of forces on an object, and (c) having fragmented and incoherent concepts of force and motion. This investigation equates non-Newtonian thinkers, naïve thinkers and novice learners as those harboring misconceptions related to Newtonian mechanics (Hestenes & Halloun, 1995).

Many of the misconceptions maintained by non-Newtonian thinkers interfere with future learning, are inconsistent with those of the science community, and exacerbate the formulation of new and scientifically acceptable conceptions (Klammer, 1998). Further, these robust alternate conceptions not only survive, but thrive as useful and intuitive beliefs, while presenting obstacles to learning physics despite academic instruction to the contrary (Dykstra, Boyle, & Monarch, 1992). As many course grades reveal, students completing an introductory physics course can satisfactorily generate numerical solutions, but remain unfamiliar with the true concepts of the course. Their success depends upon memorizing equations, employing applicable algorithms and engaging in the mechanical generation of quantitative solutions, further contributing to the formation of misconceptions.

Students harboring misconceptions (non-Newtonian thinkers) must engage in conceptual exchange, the process required to convert incorrect conceptions to ones that are consistent with that of the scientific community. Those students who are successful in undergoing conceptual change utilize certain cognitive strategies to accomplish this feat. Schraw and Dennison (1994) suggest that self-explanation, metacognitive heuristics and self-regulation are cognitive strategies used by some students to achieve conceptual change. Questions remain about the metacognitive and cognitive processes that students undergo as they confront problems. Wilson (1999) identified three such metacognitive strategies. They are metacognitive awareness, metacognitive evaluation and metacognitive regulation. Metacognitive awareness relates to an individual's awareness of his/her personal learning process, his/her knowledge of content knowledge, and what has been done and needs to be done. Metacognitive evaluation is the judgments made concerning the thinking capacities and limitations through the learning process. Metacognitive regulation occurs when individuals modify their thinking. Metacognitive regulation refers to the knowledge and use of one's abilities to make effective use of one's own cognitive resources. Ertmer and Newby (1996) add metacognitive reflection to the list of metacognitive strategies that students use for approaching learning.

These cognitive processes require a willingness and ability to recognize, evaluate and reconstruct existing beliefs on the part of the learner. As such, students must selectively attend to information, activate prior conceptual knowledge, monitor comprehension and assess the status of the new information relative to prior conceptions, while cognitively engaging in academic tasks (Hennessey, 2003).

Research Questions

Because it is important that students who successfully complete beginning physics have a strong conceptual understanding of classical mechanics, my research focused on students' understanding of classical mechanics, specifically Newton's Laws. Hence, the ultimate purpose of this study was to gain insight into the process of conceptual change undertaken by students studying Newton's Laws in beginning physics. The specific research questions are as follows:

(1) What are the strategies used by students who undergo conceptual change when studying Newton's Laws in a first semester college-level physics course?

(2) What are the strategies used by students who do not undergo conceptual change when studying Newton's Laws in a first semester college-level physics course?

(3) What is the relationship between the kind, complexity and difficulty of the concepts in an experiment and the resulting conceptual change?

This study contains elements of both quantitative and qualitative research methods and includes administering a pretest and posttest of the Force Concepts Inventory (Hestenes, Well, & Swackmamer, 1992). Further, this study espouses the constructivist view of learning, such that individuals construct their own meanings and understanding from experiences. It is because of prior knowledge that students formulate new knowledge (Driver, 1989; Gunstone, 1992). The author subscribes to the Piagetian view that evidence refuting naïve conceptions (called discrepant events) create disequilibrium, thus inducing the learner to reflect on and to reconstruct physics conceptions (Piaget, 1985).

CHAPTER 2 - LITERATURE REVIEW

Theoretical Framework

Constructivism

Classical behaviorists support the notion that all learning involves forming associations between stimuli and response (Schunk, 2000). This assumption, however, is at odds with information processing theorists who are less concerned with external conditions and more focused on the cognitive aspects of information processing occurring in the interval between the oncoming stimulus and the resulting response (Bruning, Schraw & Ronning, 1999). Classical information processing theory thus suggests a structural account of development similar to the computer processing metaphor. This metaphor suggests that the human system receives information, stores the information in memory, and retrieves the information as necessary (Schunk, 2000). Learning researchers have questioned the validity of both the classical behaviorist theory and the classical information processing theory for not fully capturing the complexity of learning and understanding. Cognitive theorists have attempted to address the deficiencies of previous theories by focusing their research on the processes and changes in mental structures resulting from incoming information and on the mental construction of new knowledge and understandings (Sanford, 1985).

Jean Piaget, a Swiss-born psychologist, focused much of his research career on cognitive development (Smith, 2001). He sought to understand the method and mechanisms through which learning increased. Piaget discovered that knowledge developed from a progressive construction of logically embedded structures that added to prior knowledge of more complex structures (Smith, 2001). Further, he discovered that individuals construct understanding through reading, listening and through experience; this theory is known as “constructivism” (Schunk, 2000).

The constructivist perspective is divergent from earlier views of education, which presumed that knowledge was transmitted from the "enlightened" instructor to the "unenlightened" student (Beatty, 2002). Rather, a current theme within the constructivist framework suggests that learning and knowledge are “built” and not transmitted, and that learners process new knowledge and understandings upon current and prior knowledge (Beatty, 2002). In so doing, the learners rely on cognitive structures to provide meaning and organization to the new information.

Though several constructivist tenets exist, the common idea asserts that cognitive processes within the human mind construct all knowledge. Radical constructivism concurs with the idea of constructing new knowledge atop existing ideas, but it challenges the notion of external reality (Beatty, 2002). According to radical constructivism, the basis of personal experiences sets the foundation for the construction of knowledge that resides within the individual. The consequence of this form of knowledge construction is that different people engage in different experiences that may result in different knowledge and "reality." Thus, the truth of knowledge and reality is relative to the individual (Beatty, 2002).

Exogenous constructivism involves the construction of knowledge within a social context. It emphasizes a strong external influence on knowledge construction such that knowledge is adequate to the extent that it accurately reflects the external world (Bruning, Schraw & Ronning, 1999). Observing, listening, acquiring experiences, and exposure to teaching promotes exogenous constructivism (Campbell, 1998).

Endogenous constructivism asserts that internal agents alter cognitive structures, thus promoting the construction of knowledge (Schunk, 2000). Those who endorse endogenous constructivism assert that adequacy of knowledge is more a matter of internal coherence than it is a match of external reality (Bruning, Schraw & Ronning, 1999). Endogenous knowledge develops from reading, memorizing and problem solving (Campbell, 1998).

Dialectical constructivism contrasts with both exogenous and endogenous constructivism in that knowledge constructions are not exclusively connected to the external world or exclusively to the cognitive workings of the mind. This knowledge paradigm is rather a combination of the preceding two traditions such that it reflects the outcomes of mental contradictions that result from one's interactions with the environment (Schunk, 2000).

Those who embrace the constructivists philosophy suggest several instructional implications. First, the instructor must understand the cognitive development of the students such that students progress at different rates (Schunk, 2000). Second, the instructor must keep students active by providing a rich, active and academically motivating educational environment (Schunk, 2000). Third, the instructor must create incongruity to assist in the construction of knowledge. Development occurs when environmental inputs do not match individual schemata. New stimuli should not be readily assimilated into existing structures but should also not be difficult to accommodate (Schunk, 2000). Finally, provide social interaction for the students. Design activities that allow student to explore other perspectives from students.

Constructivist researchers have developed models for teaching science. One model suggests that instruction must first bridge the knowledge gap between experts and novices to develop a well-organized base of knowledge resulting in informed scientific thinking (Bruning, Schraw & Ronning, 1999). Second, promote authentic learning via guided, scaffolded participation in real-world activities (Bruning, Schraw & Ronning, 1999). Third, translate declarative knowledge into procedural competencies by helping students learn to participate in scientific thinking (Bruning, Schraw & Ronning, 1999). Finally, promote student motivation with the use of authentic and student-centered exploration (Bruning, Schraw & Ronning, 1999).

Because science instruction has shifted from an emphasis of knowledge acquisition to the process of constructing scientific understanding, theorists developed another model that promotes constructive learning in the classroom by helping students carefully examine their epistemological beliefs. This can be accomplished by first, questioning the nature of science, thereby arriving at some consensus regarding the degree to which science can inform important intellectual questions (Linn, Songer, & Eylon, 1996). Second, teachers must assume a lucid scientific explanation in the classroom that will question students' naïve epistemological assumptions (Linn, Songer, & Eylon, 1996). Third, teachers must allow students to integrate disparate ideas by comparing and contrasting a variety of competing viewpoints (Schunk, 2000). One way to accomplish this goal is to use a cooperative learning environment in the classroom that increases elaboration and evaluation of scientific ideas (Tobin & Fraser, 1994).

Theorists argue that prior knowledge strongly influences the construction of new knowledge – learning by construction implies a change, replacement, addition, or modification of prior knowledge (Cobern, 1993). The focus of the role of prior knowledge in constructivism coupled with the construction metaphor summarizes the epistemological view that individuals build knowledge. Thus, this study promotes the constructivist view of learning which best provides the theoretical framework for understanding and promoting conceptual change.

Misconceptions

Theories Related to Misconceptions

A discussion of misconceptions must begin with a discussion of "concept." A logician or semanticist would define a concept as the set of real and possible objects and functions (Ferrari & Elik, 2003). A philosopher would define a concept as internal representations that serve as the vehicles for thought in the mind (diSessa & Sherrin, 1998). Schunk (2000) defines concept as a labeled set of objects, symbols or events that share common characteristics. Concepts may involve tangible objects as cars, buildings, or furniture. Concepts may be abstract constructs such as love, democracy or oneness. Experimental studies related to concepts and conceptual learning usually involves some combination of these definitions. Experimental psychology defines concepts as a list of features that are necessary to determine category membership (Bruner, Goodnow, & Austin, 1956).

Theorists proposed several ideas of a concept and arranged them in categories. First, prototype theories endorse concepts as idealized mental representation. For example, a robin is a prototypical bird; a penguin is not a prototypical bird. Other theorists developed theory-based models of concepts as elaborate mental representations.

These representations suggest that concepts are related to the knowledge of context and social structure.   Second, "actional /situated" perspectives on concepts are abstractions that apply to people acting in social settings (diSessa & Sherin, 1998).

Students attempting to integrate new and incorrect understandings with existing and incomplete understandings often end with naïve beliefs, alternate conceptions and misconceptions (Klammer, 1998).   McCloskey (1983) defines naïve beliefs as knowledge resulting from every day experiences. Chi and Roscoe (2002) suggests that naïve knowledge has two properties: it is often incorrect when compared to formal knowledge, and it often impedes the learning of formal knowledge with deep understanding.

Hammer (1996) equates alternative conceptions and misconceptions, stating that both are strongly held, stable and different from those of experts. Vosniadou (2002) describes misconceptions as student conceptions producing systematic patterns of error. Others label misconceptions as common sense beliefs that are incompatible with established scientific theory as (Halloun & Hestenes, 1985). Meyer (1993) states that misconceptions begin as previous misunderstandings that remain part of newly formed personal knowledge serving as weak foundations in the construction of new knowledge. Further, our mental models reflect our experiences and contain many assumptions that we formulate about the world around us. In this paper, alternate conceptions and misconceptions will be used interchangeable to refer to knowledge that is at odds with that of the scientific community. Naïve knowledge will refer to knowledge constructed prior to formal instruction.

Misconceptions Related to the Study of Newton’s Laws

Many misconceptions surface in the "technical" language used by students to describe natural phenomena. For example, students often confuse power with energy and combine displacement, velocity and acceleration as a single concept (Halloun & Hestenes, 1985).

The study of Newton's formulations, often counterintuitive, provides opportunities to incorporate additional misunderstandings. Many common sense thinkers distinguish two kinds of force: an impetus force and an active force (Hestenes, Wells & Swackhamer 1992). Students believe that an impetus is an internal source that keeps objects moving along. In the case of an object that is thrust upward, the 'impetus' pushes up the object until it is used up. Then according to naïve thinkers, the 'natural' vertical motion takes over and the object is returned to earth (Gunstone & Watts, 1985). This conclusion is consistent with Hestene and Halloun (1985) whose Force Concept Inventory indicated that 65% of college students polled believed that an impetus is required to maintain the motion of an object. This misconception violates Newton’s First Law, which indicates that an object will remain with constant velocity (which also includes being at rest) unless acted upon by a force. Another common misconception among physics students is that objects slow down in the absence of a net force. This conclusion was validated by the study conducted by Halloun and Hestenes (1985) in which a majority of students held that objects accelerate under a constant force. Again, this perception violates Newton's First Law. Evidence that students believe in the impetus force is evidence that Newton's First Law is not understood (Hestenes, Wells, & Swackhamer 1992).

Another common misconception is that an [active] force produces motion. This belief violates Newton's Second Law [F=ma]. For example, Watts and Zylberszyajn (1981) investigated the naïve beliefs related to force within the context of an object thrust upward. The students indicated that they believed that force at the beginning is strong (as it left the hand) and that it diminishes as the ball rises. They believed that as the motion stops (for a split second) so does the force, and then gravity is seen as pulling the ball down. In reality, force produces acceleration. Students holding this misconception do not differentiate velocity and acceleration as descriptors. Hence, students intuitively believe that motion is proportional to force (Halloun & Hestenes, 1985).

Students commonly utilize naïve reasoning to answer questions related to Newton's Third Law resulting in incorrect answers. When asked to analyze the force resulting from the collision of two dissimilar vehicles traveling at different constant speeds, students commonly responded: (a) objects with a larger velocity exert a larger force, (b) objects with larger mass exerts a larger force, (c) objects that speed up exert a larger force (Bao et al., 2002). Each of these incorrect responses violates Newton's Third Law. Students who believe in the responses commonly offered by students have failed to understand Newton's Third Law and hence, maintain misconceptions.

A common misconception among naïve students is that free fall motion is somehow related to the mass of the object. An academically gifted student was asked to predict and compare the times taken for a one-inch cube of plastic and a one-inch cube of aluminum to fall two meters. The student responded "the heavier [aluminum] one will get there first." This student substantiated his response with a claim from similar investigation that he performed earlier, supposedly observing that the heavier object reached the ground first (Gunstone & Watts, 1985).

Hestenes and Halloun (1995) introduced the terms Newtonian thinkers and non-Newtonian thinkers to the literature. They suggest that Newtonian thinkers have achieved a firm understanding of Newton's Laws, thus achieving a score of 85% on the FCI. Non-Newtonian thinkers are those with a score of less than 85% and are characterized by:

(1) undifferentiated concepts of velocity and acceleration; lacking a vectorial concept of velocity

(2) lacking a universal force concept, i.e., believing that there are other influences on motion besides forces, and unable to reliably identify the agents of forces on an object

(3) Fragmented and incoherent concepts about force and motion.

Conceptual Change

The Meaning of Conceptual Change

Different researchers have defined conceptual change differently. Dykstra, Boyle, and Monarch (1992) define conceptual change as a progressive process of refinement of students' conceptions. Niedderer and Goldberg (1994) assert that conceptual change is a process of change from the learner's prior conceptions to an intermediate conception, finally moving to a scientific conception that will likely promote learning. However, the common theme associated with these propositions is that conceptual change is the progress of reorganizing, reconstructing, realigning or replacing existing mental representations with new ones.

The literature distinguishes intentional conceptual change from unintended conceptual change. Algorithmic level learning is non-deliberate in the construction of new knowledge such that the mind acts on information without intent. The learner does not necessarily plan to modify information in a specific way; rather these constructions can occur without the learner's awareness (Pintrich & Sinatra, 2003). Deliberate effort and conscious attention are not necessary for learning to occur. Learning can occur from exposure and repetition (Pintrich & Sinatra, 2003).

Intentional conceptual change involves a deliberate attempt at radical conceptual change from one system of concepts to another (Ferrari & Elik, 2003) and contains two features. First, intentional conceptual change is goal directed (Stanovich, 1999; Ferrari & Elik, 2003; Pintrich & Sinatra, 2003). Students undergoing intentional conceptual change can monitor their process toward conceptual change while studying a particular body of information. For example, a student may set a learning goal and monitor progress toward achieving the goal. Thus, this student may allocate additional time to achieve understanding. If students are aware that the goal is not being met, they may change the learning strategy. Consequently, monitoring one's cognitive processes through goal setting promotes a change in knowledge. Second, intentional conceptual change is under the direction of the learner (Pintrich & Sinatra, 2003). These intentional processes can be overridden, redirected or ceased at will. Further, these same processes also allow the learner to evaluate goal satisfaction and redirect attention to particular information as needed. For students not engaged in intentional learning, goal-directed processing of information is controlled by other factors such as background knowledge, task difficulty and topic familiarity (Pintrich & Sinatra, 2003).

The cognitive model proposed by Kuhn distinguished between routine learning and radical conceptual change (diSessa & Sherin, 1998). Routine learning does not change the framework of the student, but merely adds new knowledge into their existing framework of knowledge; routine learning is often referred to as weak conceptual change (Carey, 1991). Weak restructuring suggests only the articulation of the relationships between existing concepts; the concepts are not changed but extended, restricted or rearranged (Carey, 1985). Strong restructuring involves changes in the concepts themselves (conceptual change) (Carey, 1985). Alternatively, radical conceptual change is the change in the ontology of the concepts themselves which suggests strong knowledge restructuring. According to Ferrari & Elik (2003), radical conceptual change is subdivided into "flawed radical change" and "positive radical change."

Flawed radical change occurs when an acceptable concept has been replaced with a faulty concept. For example, a student may replace an understood concept related to the relationship between force and mass with flawed concept suggesting that force only creates velocity. Taylor (1995) suggests that flawed conceptual change reflect a lack of conceptual expression of or reflective thinking about one's behaviors and thoughts, thus accepting ideas without question or evaluation.

Taylor (1995) proposed three arguments used to evaluate the evidence supporting positive radical conceptual change. The first argument is comparative judgment. This argument occurs when two opposing positions are evaluated against agreed-on facts. The position judged as superior is the one that best explains the facts (Taylor, 1995). Important with these systems is the agreement on the external criteria for successful explanation. The second argument occurs when an individual may desire a more powerful comparison of two conceptual frameworks that are mutually incommensurate, not agreeing on the criteria constituting evidence for their claim. Finally, the third argument demonstrates that the transition from one conceptual framework to another overcomes the contradiction inherent from earlier theory.

Luque (2003) suggests that three prerequisites necessitate intentional conceptual change. They are awareness, desire and self-regulation. First, intentional conceptual change requires that the learner first become aware of the need for change; additionally the learner must be aware of what to change. Awareness of what to change is dependent upon the type of change necessary, the learning goals of the student, their level of motivation and prior knowledge. Students undergoing intentional conceptual change must be aware of the context in which the change must occur. For example, students must evaluate the type of change required, the expected outcome, and assess the cognitive resources at his disposal to facilitate the intentional conceptual change. Second, students must be willing to change, or have the volition to change. Posner, Strike, Hewson and Gertzog (1982) indicated that incoming conceptions must be intelligible, plausible and fruitful in order for the students to allow the changes into their knowledge structures such that new conceptions must be "cognitively appealing" (Luque 2003). Finally, learners must utilize metacognitive skills of self-regulation to promote intentional conceptual change.

Demastes, Good and Peebles (1996) identify four patterns of conceptual change. They are (a) cascades of change, (b) wholesale change, (c) incremental change, and (d) dual construction. Cascade of change occurs when one conceptual alteration triggers a sequence of conceptual changes. For example, students who confuse mass and weight may suddenly comprehend the difference resulting in other conceptual changes in force. One who undergoes a wholesale change discards an alternate conception in favor of scientific conceptions, whereas in incremental changes, scientific conceptions replace alternate conceptions in increments. Finally, dual construction change refers to students who maintain two incompatible conceptions. This concept is in contrasts with those who suggest that students simultaneously maintain a manifold of competing conceptions (Taber, 2001).

The Conceptual Change Model (CCM)

Posner, Strike, Hewson and Gertzog (1982) proposed the Conceptual Change Model (CCM) to explain learning as the interaction between new and existing conceptions as related to learning. One's conceptual ecology as well as the degree to which the concept is intelligible (comprehensible), plausible (credible), and fruitful (useful) determines the likelihood of conceptual change (Hewson, 1992). Conceptual ecology provides the context in which the conceptual change occurs and gives it meaning. The ecology consists of different kinds of knowledge such as epistemological commitments, metaphysical beliefs, analogies and metaphors to help to structure new information (Hewson, 1992). Students use their conceptual ecology to determine the extent to which different conditions are met.

Satisfying these components is referred to as the status of the conception. Higher status ideas depend on the degree to which the individual understands, accepts and finds the idea useful. High status ideas are well formed, conceptually coherent and provide value for the individual holding the idea (Hennessy, 2003). These understandings enable

CCM to predict that conceptual change occurs with a concomitant change in relative status of the understandings. The conceptual conflict of an existing conception and incoming one will prevent conceptual change unless the status of the existing conception is lowered. Hence, an elevated status of one understanding in tandem to a lowered status of the existing understanding results in conceptual exchange (Hennessey, 2003).

The CCM refers to two additional categories of change: assimilation [change] and accommodation [exchange]. Assimilation is the recognition that an event fits an existing conception thus ignoring any discrepancies deemed not salient (Dyksra, Boyle & Monarch, 1992; Posner, Strike, Hewson, & Gertzog, 1982). One who experiences assimilation undergoes a change in the knowledge state without changing the fundamental belief. Further, assimilation is the use of existing concepts to deal with new phenomena (Posner, Strike, Hewson, & Gertzog, 1982). Accommodation refers to reorganizing or completely replacing the learner's conception by a new one. This mode of change implies an abandonment of the existing conception and the acceptance of a new conception, which Hewson (1982) refers to as "conceptual exchange."

Fensham, Gunstone and White (1994) argue in favor of conceptual addition, in which old ideas are not abandoned but revised incrementally. With conceptual addition, the learner sorts contexts while maintaining those concepts that are profitable for use in the explanation of another. Likewise, Linder (1993) and Taber (2001) promote the notion that learners maintain a manifold of concepts that may be summoned on the basis of the specific contexts. Maloney and Seigler (1993) build on this view and propose conceptual competition, which suggests that competing conceptions coexist within the conceptual arsenal of the learner and after a period of learning, one of these archived conceptions achieves dominance. Tao and Gunstone (1999) examined the process of conceptual change among students studying beginning physics. The research revealed that many students vacillate between alternative and scientific conceptions and from one context to another during instruction -- the conceptual change was context-dependent. The results of the study suggested that students who achieved context-independent and stable conceptual change through the process of conceptual change appeared to be able to perceive commonalties and accept the generality of scientific conceptions across contexts.

Cobert et al. (1999) sought to determine the extent to which student understanding of nature involved using concepts from other conceptual domains. The researchers found that ninth grade students did not readily integrate science concepts into daily life. Further, the study revealed a low correlation between science grade success and concepts used in discussions about the natural world. The implication is that students had not yet incorporated science into their conceptual framework. This study supports the one by Itza-Ortiz, Rebello and Zollman (2003) who also investigated the use of everyday language to explain physical phenomenon. The researchers concluded that students are more likely to identify and explain the meaning of the word as it is used in physics when they have become comfortable with the associated physics concepts.

Converting incorrect conceptions into appropriate ones require several prerequisites. One, according to von Glaserfeld (1995), is that a student must be uncomfortable and dissatisfied with the existing understanding. This "conceptual confusion" likely motivates the student to search for a new conception. Two, the student must be aware of the contradicting conception (between the existing one and the scientifically appropriate one) and reconcile them accurately. Finally, the new conception must be viable and fruitful -- the student must perceive the new conception as one that will meet the needs for a workable explanation. The new conception must have some value associated with the proposed concept such that the student will be attracted to it.

McDermott (1993) and Grayson and McDermott (1995) contributed to conceptual change theory by proposing a conceptual change taxonomy: elicit, confront, resolve and generalize. The instructor *elicits* (creates) a conceptual conflict by asking the student to predict the outcome of a situation related to a physics concept. A conceptual conflict is a difference between the accepted concept and the one held by the student. Once the difficulty has been exposed, recognized and *confronted*, the instructor requires the student to *resolve* the conflict. This strategy forces the student to address an alternate concept and to work through restructuring the concept. To be able to integrate counter-intuitive ideas into a coherent framework, they need time to *apply* the same concepts and reasoning in different contexts, to *reflect* upon these experiences and to *generalize* from them (McDermott, 1993; Grayson & McDermott, 1995).

Some researchers, however, do not accept the effectiveness of conceptual conflict in achieving conceptual change. Tsai (2000) investigated the use of conflict in resolving the conflict between students' alternative conceptions and the scientific conception using critical events, explanations and relevant perceptions. It was determined that a restructuring of an existing conception does not necessarily follow a discrepant event. In reality [according to Tsai], students try to adjust the new perception to fit their existing conception, thus working on the process of assimilation rather than on accommodation.

Hence, the use of conceptual conflict is not always effective in achieving conceptual change.

Conceptual change instruction is necessary for several reasons according to Dykstra, Boyle, and Monarch (1992). One, alternate conceptions are typically not addressed by standard instruction nor in introductory physics texts. Two, presenting students with logical arguments regarding Newtonian mechanics is ineffective because such reasoning makes little sense to students with a limited scientific context. Further, solving numerical problems do little to facilitate conceptual change within an existing conceptual context (McDermott, 1993). Three, effective physics instruction must encourage the kind of learning that leads to conceptual understanding. Such learning occurs when the individual constructs knowledge and understanding through constructivists instruction which has resulted in improved learning among students with more advanced epistemological beliefs (Windschitl, 1998). The goal of physics teaching must be to structure classroom interaction to facilitate the development of Newtonian concepts for themselves. Finally, students can construct Newtonian conceptions if they experience situations that bring them to question their own conceptions and are then facilitated to develop options that are more viable.

Encouraging students to examine their epistemology is an effective strategy for promoting conceptual change. This instructional strategy will, hopefully, result in a conceptual incoherence while prompting the students to engage in a process of changing those beliefs (Dykstra, Boyle, & Monarch, 1992). Gonzales-Espada (2003) discovered that instructing students to produce a written report regarding misconceptions resulted in an epistemological challenge of personal misconceptions. Consequently, students ended the study with changed conceptions. This study supports Zacharia (2003) who investigated the effects of an interactive computer-based simulation on conceptual understanding. This study prompted conceptual conflicts that caused students to question their epistemology and fostered significant conceptual change in physics content areas.

Windschitl (1998) compared the role of constructivists learning to that of objectivist learning situations in conceptual change. The findings suggested that the constructivist approach resulted in a significantly greater conceptual change than the objectivist approach for approximately 30% of the investigated misconceptions. Further, this study found that individuals with more advanced epistemological beliefs learned more with the constructivist treatment than the individuals with less developmentally advanced beliefs learned more with the objectivist approach.

Much research has focused on instructional pedagogy development for promoting conceptual change within a social constructivist context. Kalman (1999) investigated promoting conceptual change using collaborative groups. The researchers assigned group participants a role and directed them to resolve the misconceptions by consensus. This research study identified four common misconceptions with an attempt to utilize a social context to change the conceptions. The discussion generated during each session challenged students' commitment to the misconceptions. As a result of the interchange, this study resulted in significant conceptual change in the science content.

Hynd et al (2000) examined the role of science texts in classrooms, seeking to determine the role of cognition, attitude/motivation, and socioeconomic status in conceptual change learning from texts in the classroom. Researchers utilized participants in three science classes, one at each level of instruction; general, regular and advanced.

Results indicated that, although students and teachers rated texts negatively, and texts appeared to be ineffective in bringing about conceptual change, texts did play a central role in instruction. Teachers based lectures and labs on texts, and used texts as confirmation of information gained from lectures in lab. The researchers concluded that the relevance of physics to career goals might be the most important factor in students' willingness to learn counterintuitive concepts in physics.

Schell and Black (1997) investigated designing a collaborative classroom for adult learners within the situated learning paradigm. In this study, learners engaged in discussion, simulated group activities, articulation-reflection and verbalization of knowledge and compared problem-solving techniques with that of experts. Schell and Black found varying degrees of the acquisition of knowledge and skills from the simulated environments to the real-world situations. Courtney and Maben-Crouch (1996) discovered that learning occurs more easily when instructors and learners create a natural learning environment that engage learners in solving authentic and non-routine problems.

Vondracek sought to improve learning among "traditionally" taught disinterested high school physics students by convincing them to think about the physics they already know. His strategy was to convince students of the need to understand the vocabulary to become conceptually proficient in physics. One example, in particular, was to have students to jump from the top of a desk onto the floor without bending their knees. Of course, the students bent their knees when landing on the floor, which was a conceptual illustration of Newton's Third Law. This project ended with students who demonstrated an increased interest in physics, increased confidence in learning, and the ability to make the connections between the concepts and reality.

Teaching for Conceptual Change

The research literature advocates against engaging in heuristic teaching practices to bring about conceptual change (Hewson, 1992). Teaching for conceptual change requires the instructor to facilitate and support discourse among students by allowing them to explore and discuss developing science ideas. Further, teachers must approach conceptual change instruction from the perspective that conceptual change is the responsibility of the student; the teacher must guide the student to conceptual change (Hewson, 1992; Beeth 1995). This instructional discourse suggests that students must acknowledge others' ideas, revise their personal views when others seem more fruitful, compare their ideas to that of the scientific community and finally, exercise their new conception in a new context. The suggestion is that students must become metacognitive in their learning (Hewson, 1992).

Before the instructor can lead students to correct conceptions, the instructor must be able to diagnose existing misconceptions. The objective of the diagnosis is to elicit the students' existing conceptions and to reveal the reasons why they are held (Hewson, 1992). Meyer (1993) suggests using the think-aloud technique for diagnosing misconceptions. This technique encourages students to report everything that comes to mind while exploring an idea, topic or term as they solve problems and allows the instructor to distinguish between the student's true beliefs and how these beliefs interrelate to other concepts. While utilizing this method the instructor must be skilled enough to recognize the implications of silence and willing to probe the silence for additional information regarding the students' misconceptions. A second technique for diagnosing misconceptions allows students to teach a course topic or to elaborate on their idea encourages the student to organize their ideas and thoughts. Making presentations is a powerful strategy for promoting the comprehension and recall of material. Preparing an explanation often causes the student to struggle with examples that do not fit the students' conceptualizations. A final technique for diagnosing misconceptions is the review of students' recorded material. The organization of notes along with verbatim writings that lack any understanding relationship between concepts can illuminate students' beliefs about the main topics of a lecture, again signaling the presence of misconceptions (Meyer, 1993).

Once the misconceptions have been identified, the instructor must help the students to lower the status of existing and problematic knowledge and to raise the status of other competing ideas (Hewson, 1992). Beeth (1995) suggests ensuring a direct contrast between students’ views and the desired views, either by having the instructor to present the desired view or by allowing it to emerge from the student through discrepant events. This notion is consistent with the Conceptual Change Model in which dissatisfaction with existing conceptions is a prerequisite for conceptual change.

The instructor must provide immediate opportunities for the exercise of the desired view in explaining physical phenomena (Beeth, 1995). Questions and discussions, which focus on a related classroom demonstration, may provide the forum for students to realize that the desired conception is plausible. Students must also have the opportunity to apply their newly acquired understanding within different contexts that are both closely and distantly related to the original example (Beeth, 1995). This will demonstrate the fruitfulness of the new conception.

Conceptual Change Strategies Used by Students

Theorists define metacognition differently. According to White (1988), metacognition is the inner awareness of process rather than of just overt behavior. This awareness can refer to what one knows about content knowledge, one's learning process, or one's current cognitive state (Hennessey, 2003). Flavell (1971) suggested that metacognition is the notion of thinking about one's thoughts. Those thoughts can relate to what one knows (metacognitive knowledge), what one is currently doing (metacognitive skill) or what one's current cognitive or affective state is (metacognitive experience). An important feature of metacognition is the ability for one to think about an idea rather than to merely think with the idea. An example of metacognition is one’s ability to use ideas or conceptions to organize and interpret experiences. However, most agree that metacognition refers to the awareness of one's thinking, active monitoring of cognitive process or regulation of cognitive processes' and application (Hennessey, 1999).

The literature lists awareness, evaluation, regulation and reflection as necessary metacognitive techniques necessary for solving mathematics problems (Wilson, 1999). Metacognitive awareness is the individual's awareness of their progress in the learning process, awareness about their knowledge concerning content knowledge, and awareness about personal learning strategies. Metacognitive evaluation is the judgment made regarding one's thinking capacities and limitations as these are employed in a particular situation. Further, it is the assessment of the effectiveness of their thinking or strategy of choice. Metacognitive regulation occurs when individuals modify their thinking. Metacognitive regulation draws upon knowledge and makes effective use of available cognitive resources. The quality of regulation refers to how effectively one engages in intentional conceptual change (Wilson, 1999). Low quality regulation refers to poor planning, little monitoring; high quality regulation refers to careful planning and monitoring (Ferrari & Elik, 2003). According to Zimmerman (2001), one's self-efficacy relative to intentional conceptual change influences the degree to which one is able to make the required conceptual change. Reflection refers to the action undertaken by the student when considering the choices, actions and results have resulted from awareness, evaluation and regulation. During reflection, the learner decides on whether or not to continue or to make changes in the strategy (Schunk, 2000).

The research literature lists self-explanation as a metacognitive strategy used by students to promote conceptual change. The self-explanation strategy helps students to navigate difficult material by "talking" through the difficulty (deLeeuw & Chi, 2003). Specifically, the learner begins explaining to himself that which is difficult to understand in an attempt to recall related knowledge or to fill the conceptual gaps. Theorists indicate that self-explanation may occur spontaneously and initiated by the student or done at the direction of the instructor (deLeeuw & Chi, 2003). Research suggests that utilizing this technique results in better solutions to problem solving (Chi et al, 1989) and improved understanding while reading (Chi et al, 1994).

Hacker (1998) suggests that increasing concentration [metacognitively] is an effective strategy for promoting conceptual comprehension. He discusses a calculus student whose teacher is attempting to explain the concept of "area under a curve" by using the roller coaster metaphor. In this vignette, the student who is struggling to understand the material is quickly distracted by the thoughts of her summer vacation in which she visited a theme park that she rode. Other students in the class who are engaged in an unrelated conversation also distract her. In the face of these distractions, she continued to rely on this strategy and put additional cognitive resources on this task. This strategy eventually proves successful in filtering out the students' whispers and promoting the learning of the calculus concepts. Thus, metacognition involves active monitoring, consequent regulation, and orchestration of cognitive processes to achieve the cognitive goals (Flavell, 1976).

The focus of this investigation is to delve into the conceptual change strategies initiated and used by the student when undergoing conceptual change. Students employ self-explanation, and increased concentration at the direction of the instructor rather than because of the students' initiation (deLeeuw & Chi, 2003). Therefore, this study will focus on awareness, evaluation, regulation and reflection as the cognitive strategies initiated and used by students when undergoing conceptual change.

CHAPTER 3 - METHODOLOGY

The Case Study

The objective of this research study was to investigate the process of conceptual change used by students studying Newton's Laws. This investigation was undertaken using case study analysis.

A case study is a form of qualitative descriptive research that studies an individual or a small participant pool, drawing conclusions only about that participant or small group within that particular context (Publication Manual of the American Psychological Association, 2002). This research focused on exploration and description rather than emphasizing universality, generalizability or searching for cause-effect relationships. Further, a case study is a collection and presentation of detailed information related to a research participant or small group, frequently including the accounts of subjects themselves.

Case study researchers utilize a variety of methods, geared toward obtaining a complete view of the participant. These methods include interviews, protocol analyses, field studies, and participant-observations. Multi-modal case studies balance the results of coded data with interview data or writer's reflections. Consequently, researchers' conclusions become highly contextualized (Writing at CSU, 2004).

The case study methodology benefits research by providing much more detailed information than is available through statistical analysis. Case study advocates also suggests that researchers utilize case studies to deal with creativity, innovation and context, as opposed to statistical methods that effectively deal with homogeneous and routine behavior. Critics argue that case studies are seldom generalizable because of the inherent subjectivity of the researcher and of the qualitative data (Writing at CSU, 2004).

Ensuring the accuracy of data is important in case study analysis. Prolonging the process of data gathering on site helps to ensure the accuracy of the findings by providing the researcher with more concrete information upon which to formulate interpretations. Triangulation is a qualitative process that employs a variety of data sources as opposed to relying on a sole source of. Conducting member checks requires initiating and maintaining active corroboration in data interpretation between the researcher and participants. Collect referential materials by complementing the file of material with additional document support (CSU, 2004).

Beginning Physics - The Course

Students who participated in this research study were enrolled in a college algebra-based beginning physics course in the southeastern continental United States. The instructor of the course was also the investigator of this study. Students who completed the study received 10 points of extra credit added to their final semester score. All other students were given the opportunity to earn 10 points of extra credit for completing a writing assignment. This assignment required the students to identify two misconceptions related to Newton's Laws and, at the end of the semester, to list their understanding of those misconceptions.

Beginning physics covered 17 chapters. The list of chapter topics as they appeared in the text follows. The relative use of Newton's Laws in each chapter appears in parenthesis adjacent to the chapter topic.

(1) Intro.to Math. Conc. (0%)

(2) Kinematics: 1-D. (0%)

(3) Kinematics: 2-D. (0%)

(4) Newton's Laws (100%)

(5) Uni. Circ. Motion (50%)

(6) Work and Energy (20%)

(7) Impulse and Mom. (5%)

(8) Rotational. Kinematics (0%)

(9) Rotational Dynamics. (5%)

(10) Simple Harm. Mot.(10%)

(11) Fluids (5%)

(12) Temp. and Heat (5%)

(13) Heat Transfer (0%)

(14) Waves and Sound (5%)

(15) Linear Superposition (0%)

According to Redish (2000), training in physics offers a considerable value in a wide variety of professions, such as complex problem solving, physical modeling and estimation. The study of Newton's Laws sets the foundation for the study of force, which is a fundamental concept in science and technology that discusses the definition, the composition and the implications of applying a force. Conceptual comprehension of this topic is necessary for success in succeeding physics courses and for technical majors who study the building of structures (Writing at CSU, 2004).

The lecture portion of beginning physics met for three 50-minute sessions weekly; laboratory sessions met for one three-hour period weekly. The course instructor utilized traditional instructional methods of lecture, discussion, homework, and laboratory sessions. The instructor introduced each chapter by providing advanced organizers in the form of text reading, handouts and links to related web sites. The lecture commenced with a general overview of the chapter and with a discussion of how the subject under discussion fits into the scheme of physics. This strategy enabled the instructor to promote the building of new knowledge on prior understandings. Next, the instructor introduced topical concepts, appropriate mathematical units and finally the mathematical models (equations) used to predict the outcome of physical phenomena. As in most college-level courses, students were required to complete a series of homework problems from each chapter designed to help with understanding the concepts.

The course schedule called for five examinations, each covering three chapters. A combination of homework, one extra credit quiz and the test score, itself comprised one exam score. In each of the twelve-two-hour laboratory sessions, students performed closed-ended, quantitatively based laboratory examinations geared toward confirming known information. The written report is not a formal one. Students merely completed the data sheets provided in each assignment. Students were to consider significant digit rules when reporting data and calculations. Following is a schedule of laboratory assignments undertaken by students in Physics I:

(1) Significant Figures
(2) Measurement and Errors
(3) Vectors
(4) Acceleration due to Gravity
(5) Newton's 2nd Law
(6) Centripetal Force
(7) Torque
(8) Hooke's Law and SHM
(9) Wave Motion
(10) Resonance
(11) Temp. and Expansion
(12) Specific Heat Capacity

Each student was required to complete the course final exam (no exemptions). It was a multiple choice, machine graded exam. The twenty-five-question exam was comprehensive and included approximately two questions from each chapter. The order of the chapters from which the questions come was random. Students will have had two hours to complete the final exam.

The final grade in this course was comprised of the sum of the four highest exam scores (the lowest exam score is dropped), the highest eleven laboratory assignment scores (the lowest lab score is dropped) and the final exam score. The maximum score was 1000 points. Each student received a grade on the basis of the following scale: 1000-900 = A, 899.99-800 = B, 799.99-700 = C, 699.99-600 = D, below 600 = F.

The Force Concept Inventory

The Force Concept Inventory (FCI) developed by Hestenes, Wells, and Swackhamer (1992) served as the assessment instrument for gathering data on the student misconceptions (Appendix A). The test contained 25 questions that assessed each student's knowledge and use of Newton's Laws and applicable concepts. According to its authors, instructors often utilized the FCI to evaluate instruction, to place students in the correct course or to serve as a diagnostic tool. Many instructors used it to identify, classify and raise the awareness of student misconceptions (Hestenes, Wells, & Swackhamer, 1992). This study utilized the FCI as a diagnostic to identify the presence of misconceptions held by students as related to Newton's Laws.

The FCI was unique in that it assessed student understanding in six areas of basic Newtonian physics. These areas were (a) kinematics, (b) First Law, (c) Second Law, (d)

Third Law, (e) Superposition Principle, and (f) Kinds of force. The following question is an example of a question used to determine the student's understanding of a kinematics principle:

> Two metal balls are the same size, but one weighs twice as much as the other. The balls are dropped from the top of a two-story building at the same instant of time in the absence of friction. The time it takes the balls to reach the ground below will be:
>
> a. about half as long for the heavier ball
>
> b. about half as long for the lighter ball
>
> c. considerably less for the heavier ball, but not necessarily half as long
>
> d. considerably less for the lighter ball, but not necessarily half as long.
>
> e. about the same time for both balls.

The intuitive non-Newtonian response is that the heavier ball would reach the ground first. Students who are non-Newtonian thinkers would likely choose "c" believing that the heavier object would hit the ground first. Thus, choosing "c" suggests a weak conceptual framework and the presence of an alternate conception in kinematics. Students, however, with a stronger conception understand that in the absence of friction, time-in-flight is mass-independent, and would thus choose "e."

Many physics professors have examined each question contained in the FCI and concede that each question provides one and only one Newtonian response among the five alternatives. Thus, "….the *face validity* of the test is beyond reasonable doubt" (Hestenes & Halloun, 1995). The authors of the FCI addressed content validity, which is the degree of accuracy of the final student score by estimating the probability of false negatives and false positives. Qualitative analysis of responses by Newtonian thinkers suggest that the probability of false negatives (Newtonian thinkers choosing a non-Newtonian response) to be less than ten percent. This is because the Newtonian response is obvious to Newtonian thinkers; false negatives can be attributed to carelessness or inattention (Hestenes & Halloun, 1995).

The authors of the FCI minimized false positives two ways. One way was by probing each conceptual dimension with several questions involving different contexts and viewpoints. Thus, false positive questions can be partially compensated by a non-Newtonian choice. The second way is to introduce non-Newtonian distracters into each FCI question that to non-Newtonian thinkers, appear reasonable. The choices for these alternatives have been confirmed by extensive student interviews (Hestenes & Halloun, 1995).

The FCI test has been administered to over 1500 high school and 500 university students with similar resulting scores. Moreover, various researchers have replicated results of the FCI's predecessor, the Mechanics Diagnostic test, many times. For example, three researchers administered the FCI at a major southwestern university. Following are the pretest/posttest scores achieved by the students who were instructed by each of the three researchers that taught one regular section of Physics I: 34/63, 36/68, 52/63. Consequently, researchers confirmed the reliability of the FCI.

Procedure and Time Frame

Diagnosing Students' Misconceptions

The overall plan of the study is outlined in Appendix B (The Time Sequence for the Investigation). The study proceeded with the administration of the Force Concepts Inventory (Appendix A) as a pre-test and coincided with the study of Chapter 1. All students enrolled in the researcher's/instructors' course completed the FCI.

Each question on the FCI was related to a taxonomy of six possible inventory items (kinematics, First Law, Second Law, Third Law, superposition principle, kinds of forces). The researcher tallied all responses from the pool of participants against the taxonomy, and recorded the total number of correct responses on the spreadsheet. A large number of responses next to "kinematics", for example, indicated a large number of correct responses and suggested that relatively few misconceptions existed for this Newtonian concept. Relative small numbers indicated the presence of more misconceptions. The researcher ranked the misconceptions based on incorrect responses and utilized the top two misunderstood concepts as the basis of this investigation.

Selection of the Research Participants

Immediately after the administration of the FCI, the researcher reviewed all FCI responses, dividing the responses into two groups. One group represented students who responded incorrectly to Inventor Item #9 thus demonstrating weak comprehension in the first of the two conceptions; the other group represented students who responded incorrectly to Inventory Item #18 demonstrating weak comprehension in the second of the two conceptions. The researcher randomly selected five students from each of the two pools of students with the weak conceptions to participate in the study. Thus, the study began with five students having strong misconceptions in the first concept and five students having strong misconceptions in the second concept. The total number of participants was ten students.

The researcher extended an invitation to students not selected as primary participants to participate by submitting a journal containing their misconception from Chapter 4 (Newton's Laws). In addition, the researcher invited any students interested in participating in Teaching for Conceptual Change phase of the investigation to participate for the benefit of receiving the additional instruction.

Once the investigator identified the ten student participants, each student completed a Student Demographic Survey (Appendix C). This survey collected information on age, ethnicity, academic major, and math and physics courses taken. The investigator utilized the information from this survey to analyze the data. This study did not target participants based on age, gender, ethnicity, etc.

Allowing all interested students to participate in the study provided additional benefits. One, it protected the researcher from not having sufficient participants in the event that students withdrew from the course before all of the data had been collected. Two, this negated any ethical issues associated with some students that may have received a "dual dose" of instructions related to the study of Newton's Laws while others may not have had the same opportunity. In all, 107 students completed the FCI; out of those, twenty-one students expressed an interest in participating in the study as primary research participants. However, this investigation only collected data for ten students (five for each of two misconceptions). The ten students were randomly selected from the pool of the twenty-one students.

Traditional Teaching of Newton's Laws

The beginning physics course (including research participants and non-participants) continued with the study of Newton's Laws. The class was instructed using the traditional lecture, homework, lab and exam format. Newton's Laws appeared in Chapter 4 of the class textbook. It is important to note that at this point in the investigation, the participants had been selected, and the misconceptions had been chosen. The next part was to promote conceptual change among the participants (Appendix B).

Teaching for Conceptual Change

This part of the investigation occurred in three phases (Appendix D). Phase I of this part of the investigation allowed the students articulate their personal understanding of the conception under study. Phase II provided the student with a problem (discrepant event) associated with the misconception, asking the student to make a prediction, observe the outcome and record any measurements. Phase III allowed the student to confront and to compare their conception to that of the concept the scientific community accepts. The role of the investigator was be to help the student make his/her thinking explicit and to clarify the view(s) of the student.

Phase I – Acknowledging Their Understanding. The researcher discussed the results of the FCI related to the misconception under review with each student (on an individual basis). The discussion focused on encouraging the student to reveal personal ideas, provide support for these ideas to, to articulate their understanding about the physical phenomenon and to explain their responses on the FCI. The investigator repeated this phase with each of the five students for the first misconception studied. The investigator also conducted this phase with each of the five students for the second misconception. All sessions were videotaped.

Phase II – Collecting Evidence. The researcher designed a problem (discrepant event) related to the first misconception under study. The same problem was presented to each of the five student in which the student was to predict and record the potential outcome (Brandsford, et al, 2000). The student recorded his/her prediction on the Discrepant Event Prediction (Appendix E). The researcher performed the problem, and the student observed the outcome, and recorded any measurements. This phase was repeated with the second set of five students utilizing a second discrepant event.

The researcher then initiated a dialogue with the student concerning the outcome of the event. The objective of the discussion was to encourage the student to compare his current concept with that of the event, thus confronting the incorrect conception. Through this discussion, the student began to regard the new conception as intelligible and to reconsider the old conception in light of the new one.

The second goal of this stage of the investigation was to determine the conceptual change strategies used by the students while undergoing conceptual change. This discussion focused on the four categories of strategies that form the basis of this investigation: awareness, regulation, evaluation, and reflection (Wilson, 1999; Ertmer & Newby, 1996). The research participant and the investigator engaged in a dialogue on an individual basis that would utilize a set of prompters to guide the discussion (Appendix F). Each student was asked to utilize the talk-aloud method during the interview. The data from this part of the investigation was recorded on videotape, transcribed and used for later analysis. This was repeated with the second misconception.

Phase III – New Knowledge Activity. The objective of this phase was to provide an opportunity for the student to utilize the new ideas in a different context. Students assigned to study the Hockey Puck misconception completed an activity in which they identified the forces acting on a golf ball moving in free-fall flight (see Appendix I). Students assigned to study the Elevator misconception completed an activity that focused on an outer space vehicle equipped with four rockets: one on the front, rear, top and bottom (see Figure 4). The vehicle contained two force meters, one capable of registering positive or negative forces in the x direction and the other capable of registering positive or negative forces in the y direction. This activity involved firing one or more of the rockets and asked the student to determine which of the scales registered the forces.

Phase IV – Conceptual Change Strategies. Conceptual Change Strategies, focused on the strategies utilized by students who successfully underwent conceptual change. They were (a) dissatisfaction with the existing conception; (b) ability to comprehend the new conception (intelligibility); (c) believing the potential conception to be true (plausible); (d) finding the new conception usefulness (fruitful) proposed by Posner, Strike, Hewson and Gertzog (1982) in their Conceptual Change Model (CCM). Table 2 outlines the research findings relative to the hockey puck misconception and CCM. Wilson (1999), and Ertmer and Newby (1996) listed awareness, evaluation, regulation and reflection as strategies required for undergoing conceptual change. Table 3 provides a summary of the conceptual change strategies.

The researcher also sought to determine the relationship between the nature of the concept and the resulting conceptual change. To accomplish this, the interviewer prepared a list of prompters to help guide the discussion which utilized the talk-aloud method (Appendix H). The data from this part of the investigation was recorded on videotape, transcribed and used for later analysis (Wilson, 1999).

The same FCI that was previously used as the pretest served as the posttest. The research investigator administered the posttest after completing the study of Chapter 4. The research investigators examined the FCI posttest results pertaining to the misconception studied, searching for evidence of conceptual change.

This was accomplished by comparing the posttest results to the corresponding pretest results related to the misconception. Students underwent successful conceptual change if students chose the correct posttest selections on the FCI.
Note: to alleviate any ethical concerns, the extra instruction provided by Teaching for Conceptual Change was made available to all students. However, only the data from the research participants was recorded and analyzed as research data.

Analysis of Data

The researcher read transcripts line-by-line searching for processes, actions, assumptions and themes that emerged during the discussions with students (Ryan & Bernard, 2000). In addition, the researcher searched for metaphors, word repetition and for shifts in content (Agar & Hobbs, 1985). The researcher generated a codebook as a strategy for bringing out themes (Ryan & Bernard 2000). Codebooks are organized descriptions that describe behaviors, ideas, values, or any other themes of interest. In addition, the descriptions should included criteria for inclusions and exclusions, and exemplars of real text for each theme.

Establishing a profile is important in the analysis of the data. This involved determining the relationship of the themes, concepts, beliefs, and behaviors. As the profile took shape, the researcher searched for negative cases – those that do not fit the profile. Negative cases disconfirm parts of the profile or suggest that a new connection may exist (Ryan & Bernard, 2000).

Interview Strategy (Misconception #1 – Hockey Puck)

The researcher assigned Aaron, Ben, Caleb, Doug and Edward to Misconception #1. Each of these five students incorrectly believed that a force (as in an impetus force) striking a hockey puck continued with the hockey puck through the remainder of the trajectory. This flawed reasoning was the result of the students' understanding of Newton's Second Law (F=ma).

The researcher dealt with this misconception by leading the student to understand the following as a way to associate the Atwood Pulley concepts related to the hockey puck scenario: the presence of a positive net force resulted in the presence of a positive acceleration; the presence of a negative net force resulted in the presence of a negative acceleration (deceleration). Therefore, the researcher's strategy objective was to lead the student to understand that if the hockey puck underwent a negative acceleration (deceleration), the force of the stick, which provided a positive acceleration, must not be present. The researcher focused this conversation within the context of pushing a car, realizing that pushing it resulted in a positive acceleration; removing the push from the car resulted in a negative acceleration.

The new-knowledge activity presented by the researcher asked the student to identify the forces acting on a golf ball at three positions. They were: (i) sitting on the tee, subjected to the force of the golf club; (ii) along the first part of the free-fall trajectory; (iii) at the crest of the trajectory; (iv) and at rest back on the ground.

Interview Strategy (Misconception #2 – Elevator)

Fred, Gary, Harold, Isaac, and Jack possessed a weak understanding of the relationship of the upward tension force and the downward weight force. Their shallow understanding of Newton's Second Law resulted in this misconception.

The researcher sought to lead the students to a conceptual understanding of the relationship between opposing vectors under the four kinematic conditions of (a) upward motion with an acceleration of zero m/s^2; (b) upward motion with non-zero acceleration; (c) downward motion with an acceleration of zero m/s^2; (d) downward motion with non-zero acceleration.

The strategy utilized by the researcher involved the use of an Atwood Pulley, which contained a spring gage with suspended masses from each end. The spring gauge measured the tension in the string that generated from the suspended mass. When at rest, the spring gauge registered the weight of the suspended weight. When moving upward or downward at constant speed, the gauge read, again, the weight of the suspended weight. But, when the mass was accelerated upward, the spring gauge registered more than the weight; when the mass was accelerated downward, the spring gauge registered less than the weight.

The students selected to participate misunderstood the concept of adding vectors. Most had no idea about how Newton's Second Law governed the motion or magnitude of the forces within this context. Thus, the initial portion of the discrepant event focused on leading the student to understand that, equal weights (as measured by the student) resulted in a net force of zero Newtons and zero acceleration. Next, the researcher moved the student toward examining the relationship between the differing masses and the ensuing acceleration. This was done by adding mass to one side and allowing the system to respond (the heavier side accelerating downward and the lighter side accelerating upward). The student would be able to record the weight reading from the spring gage, thus coming to the proper conclusion. The researcher merely asked the students to look for a qualitative change in the reading of the spring gauge rather than a quantitative one.

The researcher sought to reinforce the corrected concept gained from the first interview through a second interview and to utilize the new concept within a different context. The activity, which, represented the new context for this "elevator" misconception, began with a person located within a space vehicle traveling in outer space. The vehicle contained rockets pointed in four directions and numbered as described:

Here, the student's objective was to determine the force that would register in the x direction and in the y direction under various conditions (see Figure 4).

CHAPTER 4 – RESEARCH FINDINGS

Introduction

This portion of the dissertation will discuss the findings from the research investigation. This will occur in three sections. The sections are The Chosen Misconception, The Hockey Puck Misconception, and The Elevator Misconception.

The first section entitled "The Chosen Misconceptions" reviews the student responses of the Force Concepts Inventory (FCI) pretest and outlines the method used by the researcher to choose the misconceptions that would form the basis of this study. The researcher referred to the two misconceptions as "The Hockey Puck Misconception," and "The Elevator Misconception."

The second section entitled, "The Hockey Puck Misconception," focuses on the process of conceptual change of five students assigned to study this particular misconception; each of the five students' pseudonyms were Aaron, Benjamin, Caleb, Doug, and Edward. The researcher further subdivided the discussion into four phases: (a) Phase I – Acknowledgment of Understanding, (b) Phase II – Collecting Evidence, (c) Phase III – New Knowledge Activity, and (d) Phase IV – Conceptual Change Strategies.

The final section of this chapter entitled, "The Elevator Misconception" focuses on the process of conceptual change of five students assigned to study this particular misconception; each of the five students' pseudonyms were Fred, Gary, Harold, Isaac and Jack. Again, the researcher further subdivided this discussion into four segments: (a) Phase I – Acknowledgement of Understanding, (b) Phase II – Collecting Evidence,

(c) Phase III – New Knowledge Activity, and (d) Phase IV – Conceptual Change Strategies.

The Chosen Misconceptions

Each question on the FCI was related to a taxonomy of six possible inventory items (kinematics, First Law, Second Law, Third Law, superposition principle, kinds of forces). The researcher tallied all responses from the pool of participants against the taxonomy, and recorded the total number of correct responses. A large number of responses next to "kinematics", for example, indicated a large number of correct responses and suggested that relatively few misconceptions existed for this Newtonian concept. Relative small numbers indicated the presence of more misconceptions. The researcher ranked the misconceptions based on incorrect responses and utilized the top two misunderstood concepts as the basis of this investigation.

Out of the 109 students who participated in the study, only seven students correctly identified answers on the FCI pretest associated with the concept referred to as Canceling of Forces and Superposition, thus likely maintaining a relatively high amount of misconceptions associated with this Newtonian concept (see Table 1). Items #9 and #18 were both related to canceling of forces and superposition.

Item #9 referred to a hockey puck moving horizontally before experiencing an impulse (a sudden force) perpendicular to its velocity (see Figure 1). Thus, the first misconception was titled, "The Hockey Puck Misconception." Item #18 referred to an elevator moving vertically at constant speed and asked the examinees to identify the forces acting on the elevator (see Figure 3). Consequently, the second misconception was titled, “The Elevator Misconception.”

Items #9 and #18 were both associated with the “Superposition” category and the “Canceling of Forces” concept. Superposition, the adding of forces, results when two or more forces simultaneously act on an object and allows the analyst to determine a net force, thus predicting the behavior of an object experiencing these forces. “Canceling of forces” refers to a specific situation in which one force is superimposed onto another force such that the net force is zero Newtons; the first force “canceled” the second force. Both misconceptions involved two or more forces simultaneously acting on the object (the hockey puck or the elevator).

The Hockey Puck Misconception

Inventory Item #9 (see Table 1) asked the student to consider a hockey puck moving under constant velocity that suddenly experienced an impulse (a force) perpendicular to the direction of travel (see Figure 1). This question asked the student to identify the forces acting on the hockey puck after the application of the impulse. The choices were:

a. The downward force due to gravity and the effect of air pressure

b. The downward force of gravity and the horizontal force of momentum in the direction of motion.

c. The downward force of gravity, the upward force exerted by the table, and horizontal force acting on the puck in the direction of motion.

d. The downward force of gravity and an upward force exerted on the puck by the table

e. Gravity does not exert a force on the puck; it falls because of the intrinsic tendency of the object to fall to its natural place

The correct answer was “d” which eight students chose. Fifty-one students chose “c”, which suggested that students believed that an object in motion was moving under the influence of an impetus force. These responses were entirely consistent with studies performed by Hestenes, Wells and Swackhamer (1992). Twenty-eight students chose “b”, which indicated that they believed that momentum was a force and further did not accept the notion that a surface exerted an upward force on any object it supported. Finally, ten students chose “e” believing that gravity did not produce a force, again a misconception. Consequently, superposition and the canceling of forces ranked as the least understood concept among examinees.

This research strategy focused on moving the student toward three understandings: (a) a net positive force results in a positive acceleration; if a hockey puck experiences a positive acceleration, a positive force must be present; (b) a net negative force results in a negative acceleration; a hockey puck experiencing a negative acceleration must also be exposed to a negative force; (c) a hockey puck exposed to a zero net force will result in zero acceleration. A hockey puck positively accelerates because of the positive force on the hockey stick; a hockey puck negatively accelerates because of the negative force of friction. Thus, the force of the hockey stick on the hockey puck could not remain with the hockey puck during its total trajectory because the acceleration is negative.

The researcher sought conceptual change by utilizing a four-phase approach. The intent of Phase I, Acknowledgment of Understanding, was to encourage the student to discuss and explain their FCI responses, to articulate and to provide support for personal ideas, and to articulate their understanding about the physical phenomenon as related to the Teaching for Conceptual Change Lesson Plan (see Appendix D).

The goal of Phase II, Collecting Evidence, was to confront the students' understanding with reality by utilizing the discrepant event. With the Hockey Puck Misconception, this was accomplished by considering the acceleration of the Atwood Pulley (see Figure 2) under two conditions: (a) supporting equal masses which equated to zero net force, and (b) and supporting unequal masses, suggesting a non-zero net force. Finally, the researcher and the student performed the discrepant event and observed the outcome. This strategy focused on moving the student toward understanding that when the net force is zero Newtons (supporting equal masses), the resulting acceleration is zero m/s^2; when the net force is not zero (unequal masses) Newtons, the system accelerates.

Phase III, The New Knowledge Activity, occurred after a formal study of Newton's Laws and began with a discussion of the students' understanding of force, mass, acceleration, velocity, and the misunderstood concept. If, at this point, the student held to the prior conception, the researcher engaged the student in an additional discussion, attempting to promote conceptual change. This discussion centered on the idea of pushing an automobile and the understanding that "pushing" suggested a positive net force and a positive acceleration and that "not pushing" suggested a net negative force and a negative acceleration; a car cannot positively accelerate without a net positive force. The researcher provided a New Context Activity for the student a (see Appendix I) in which the student utilized the new concept within a new context. The new context activity for the hockey puck misconception involved a golf ball resting on a tee that, after being struck with a golf club, was sent into free-fall flight, finally coming to rest on the ground. The researcher asked the student to identify all forces acting on the ball at four positions along the trajectory: (a) on the ground before being struck by the club, (b) a position before the maximum height, (c) at the maximum height, and d) at rest on the ground.

Phase IV, Conceptual Change Strategies, focused on the strategies utilized by students who successfully underwent conceptual change. They were (a) dissatisfaction with the existing conception; (b) ability to comprehend the new conception (intelligibility); (c) believing the potential conception to be true (plausible); (d) finding the new conception usefulness (fruitful) proposed by Posner, Strike, Hewson and Gertzog (1982) in their Conceptual Change Model (CCM). Table 2 outlines the research findings relative to the hockey puck misconception and CCM. Awareness, evaluation, regulation and reflection are strategies required for undergoing conceptual change (Wilson, 1999; Ertmer & Newby, 1996). Table 3 provides a summary of the conceptual change strategies.

The researcher assigned Aaron, Benjamin, Caleb, Doug and Edward to study the hockey puck misconception. The commonality between all five students is that they all began the investigation with the same misconception about an impetus force which they adopted as a way to explain the persistence of motion in the absence of an external agent (Halloun & Hestenes, 1985). Further, their chosen pretest answers suggested that they believed air pressure and momentum were forces and that the force creating the acceleration for the hockey puck continued along the trajectory. Consequently, their "common sense" experiences resulted in strongly held and scientifically inconsistent ideas. Of the students assigned to study this misconception, Aaron, Benjamin and Caleb experienced conceptual change; Doug and Edward failed to undergo conceptual change.

Phase I - Acknowledgment of Understanding – Aaron

Aaron was a 19 year old Hispanic male majoring in mechanical engineering technology. His high school grade point average (GPA) was 3.45/4.0 and his college GPA was 3.33/4.0. Aaron enrolled in AP physics and calculus and Honors level physical science, physics, Algebra I and II, geometry, and trigonometry. As of this writing, Aaron's academic standing in Physics I was 63%. On the FCI, Aaron's answer to question #9 was selection "a." His impression was that the downward force due to gravity and the effect of air pressure acted upon a hockey puck in motion.

At the start of the investigation, the researcher asked Aaron to elaborate on his FCI response to question #9. Aaron stated that:

Researcher: Here's the question. You have a hockey puck moving along ice. The puck will move and experience a hit. The question …the main forces acting along the path is….and you answered that gravity and the effect of air pressure.

Aaron: What were the other answers? I don't remember?

Researcher: Ok, the other answers were, the second one -- the downward force of gravity and the horizontal force of momentum in the direction of motion, the third one -- the downward force of gravity, the upward force exerted by the table, and the horizontal force acting on the puck in the direction of motion, the fourth one – the downward force of gravity and the upward force exerted on the puck by the table, and the fifth one – gravity does not exert a force on the puck; it falls because of the intrinsic tendency of the object to fall to its natural place. Let me just tell you what's going on. You have a hockey puck on ice and the puck is going get hit. The question is that after the puck gets hit, what are the forces that remain after it gets hit?

Aaron: Eventually, if it's on ice its friction and will slow it down. Because of the ice, the original inertia will cause it to remain on its original path so the force will eventually come to rest (see Figure 1).

Researcher: Ok, what is inertia?

Aaron: Inertia is the, an object's desire to keep moving.

He, therefore, correctly identified friction as one of the forces present during the motion of such an object. Aaron's conceptual notion of inertia was correct in that he stated that, "inertia is an object's desire to keep moving." However, he incorrectly stated that the force that created the acceleration would "eventually come to rest."

Phase II - Collecting Evidence

The discussion related to the discrepant event centered on predicting the behavior of masses suspended by the Atwood Pulley (see Figure 2), first with equal masses, and finally with unequal masses.

Researcher: As far as this system [the Atwood Pulley] that is set up here, what do you think would happen if these two masses were equal here, realizing that this is a pulley with a connecting string and two masses. What do you think would happen with these two masses were equal?

Aaron: Um, I would say that they would be equal and be equal distance from the pulley and equal position from the ground and at the same level.

Researcher: Ok, and what do you think would happen if one side had greater mass than the other did?

Aaron: It would bring the mass that's greater down.

Aaron incorrectly believed that equal masses would result in the self-leveling masses; he correctly believed that unequal masses would move, "bringing" the heavier mass down.

After Aaron's prediction, the researcher and Aaron discussed the outcome of the discrepant event:

Researcher: Alright, you've made your prediction about what would happen with this set up. Now, let's look at this side here (pointing to one of the masses). Based on the fact that they're [the masses] the same what did you think would happen if they're the same?

Aaron: I thought that they would level themselves out.

Researcher: Let's see. They're level here (leveling the two masses). What about here, are they level here (moving them to a different level) ?

Aaron: Kind of level.

Researcher: What about right there?

Aaron: They're not level.

Researcher: So, then it doesn't matter whether they are level or not. It doesn't matter whether they are level based on the mass.

Aaron: Right.

Researcher: Now if I go and add some mass to one side, what do you think is going to happen?

Aaron: Um, I don't think that they'll stay still like they are now in equilibrium.

Researcher: Ok, what do you see them doing? They started from rest and…..

Aaron: Now it's bringing the heavier one down.

Researcher: What about as far as the velocity. Is it changing?

Aaron: Yeah, its accelerating

Researcher: Ok, the system is accelerating. It starts from rest and it increases the velocity. So, then, what does that say about… if these two masses are not the same then that results on what….

Aaron: It would give the heavier one an acceleration.

Researcher: Correct. What was different about your prediction and your observations?

Aaron: Well, I thought presumably they would be level when they were equal.

Researcher: And where did you get the idea that they would level themselves out?

Aaron: Well, I guess a balance like that (pointing to a two pan balance), they would balance themselves out if they're the same weight.

Aaron realized that his initial prediction was incorrect; the equal masses did not self-level, but remained stationary. Further, he realized that unequal masses created an acceleration.

The researcher asked about Aaron's understanding of the effect of net force and mass on acceleration to gain an additional understanding of Aaron's conception. He correctly indicated that:

I'd say that the greater the mass and of course, the greater the mass it will take…The greater the mass the greater force needed to accelerate it.

The next portion of the discussion centered on answering the original question: what were the forces present during the kinematic motion of a hockey puck.

Researcher: Let's talk about the hockey puck and the force. So, here's the hockey puck and you go and hit it. Does the force remain with the puck or does it stop?

Aaron: The force goes with the puck and keeps going.

Because Aaron held to the prior conception, the researcher sought understanding from Aaron by discussion of creating a positive acceleration by pushing a car.

Researcher: Well, think about a car that you are pushing. While pushing it is the car accelerating?

Aaron: It's accelerating.

Researcher: Once you move your hand from the back of the car, what does the car do?

Aaron: stops accelerating…….

Researcher: If I hit the hockey puck, while I'm hitting it, while it's in contact with the stick what is the velocity of the hockey puck going to do?

Aaron: Increase.

Researcher: Once you remove the stick from the puck, what does the velocity do? Increase, decrease or remain the same.

Aaron: Decrease.

Researcher: So, in decreasing, is the force still hitting it?

Aaron: No.

Researcher: Is that force still active on the hockey puck?

Aaron: No

Researcher: So, let me go back to this question here. The main forces acting on a hockey puck after being hit with a force are….you've already said the downward force of gravity. That's one of them. You chose air pressure.

Aaron: I just chose that one. I just kind of made that one up.

Researcher: Do you think that air pressure affects a hockey puck?

Aaron: It's so small.

Researcher: What about the hockey stick? Is that going to be one of the forces acting on the puck as it's moving along?

Aaron: Not as it's moving along, and eventually it will not when it looses contact.

Researcher: Correct.

When asked during this discussion, Aaron initially indicated that the force that created the acceleration (the kick) continued with the object through its entire trajectory. However, after a series of discussions, Aaron then expressed that the force ceased after making contact with the puck.

Phase III - The New Knowledge Activity

After a formal study of Newton's Laws, the researcher commenced the second phase by asking Aaron to complete the "new knowledge" activity which asked students to identify the forces on a golf ball along its trajectory (see Appendix I):

Researcher: Let's talk about the concept that I just had you to look at. Describe it.

Aaron: A golfer is hitting a ball rest. It's on a tee. It's going back to rest at the end of it's motion.

Researcher: So, what are you asked to look at?

Aaron: The forces acting on the ball while it's in air and being hit.

Researcher: And what did you come up with? Let's look at the first one….at the first instance, the question asks you identify the force acting on the ball while it's being hit. What did you come up with?

Aaron: I put that golfer's club because it was at rest and um, since we're not talking about rest before, we're just talking about the club.

Researcher: Any other force?

Aaron: Not really.

Researcher: Is the ball accelerating?

Aaron: Yes.

Researcher: While it's in contact with the ball?

Aaron: Yes.

Researcher: Let's look at the second question. At position two after the ball is struck by the club what are the forces acting on the ball?

Aaron: I just put gravity but I didn't have enough time and I wasn't thinking about anything else. I guess there could be another force because it might, the ball would be accelerating….

Researcher: The ball would still be accelerating.

Aaron: Um….well….actually no, it wouldn't still be accelerating. It would just be gravity accelerating.

Researcher: And what about when it reaches the maximum height at three?

Aaron: It wouldn't be moving but gravity and the upward force would be equal so it wouldn't be moving.

Researcher: And what about when it hits the ground at number four?

Aaron: When it hits the ground and comes to rest I said weight and normal force but gravity would be pulling down to the ball.

Aaron completed the new knowledge activity, answering all questions correctly. He correctly identified all appropriate forces at each of the four points along the kinematic trajectory. His written response for Question #2 and #3, which asked him to identify the forces on the golf ball at two different positions along its trajectory, suggested conceptual comprehension as well as conceptual change, thus he did not include the force from the golf club on the ball as the ball continued along its trajectory.

The researcher engaged Aaron in a conversation by asking him to describe the concepts that talked about and to give his idea about force:

Aaron: Force occurs when any another object comes in contact with another one that's at rest or pushing or anything like that or when it's constant force like gravity will be always acting on a pen to stay on the desk and there's a force acting upon it. So, there's always equal and opposite force.

Researcher: If you think back about this exercise that I gave you and you look at item #2 and #3, talk to me about why you think what you think about those two?

Aaron: Well, I put for two only because gravity I figure that there is no other force pushing the ball up other than the initial force given by the club and the only real force acting on it would be gravity. There's also air resistance….air resistance would also be a force acting against its motion. But I thought that that would be kind of minute, so I just said gravity.

Researcher: Does air friction act on it?

Aaron: Yes.

Researcher: And when along the path does the air friction act?

Aaron: It would act all along it as long as the ball is in motion in the air.

He elaborated on the forces acting on a hockey puck moving along its kinematic path, thus demonstrating his understanding of the topic.

Aaron initially revealed the following three misconceptions: (a) Aaron believed that the impetus force continued with the hockey puck; (b) he believed equal masses suspended from an Atwood Pulley would self-level; and (c) he was unsure about the relationship between the net force and acceleration (see Table 4). Based on his responses in this investigation, Aaron underwent conceptual change.

Phase IV - Conceptual Change Strategies

Aaron initially believed that an object "kicked" with a force perpendicular to the initial velocity vector experienced a downward force due to gravity and air pressure. He further believed that, "the force goes with the puck and keeps going." At the end of the first phase, the researcher asked Aaron if the hockey stick would act on the puck as it is moving along. Aaron stated that:

…not as it's moving along, and eventually it will not when it looses contact.

Thus, Aaron was on the road to conceptual change. He demonstrated intelligibility and plausibility in the new conception. However, he did not demonstrate fruitfulness of the new concept.

Aaron utilized conceptual conflict to rearrange his concepts, thus undergoing conceptual assimilation. Aaron's "strong" restructuring (Carey, 1985) of concepts involved a complete replacement of concepts as opposed to a rearrangement of concepts. Moreover, as an academically strong student, he benefited more from the conceptual conflict than did his academically weak counterpart which is consistent with Dreyful, Jungwirth and Eliovitch (1990). This resulted in Aaron achieving a cascading effect in his conceptual change (Demastes, Good & Peebles, 1996).

Aaron's conceptual change strategy exhibited the use of metacogitive awareness during this investigation (see Table 3). Toward the end of the second phase, the researcher asked Aaron about the level of difficulty in understanding the concept. Aaron believed that, "If I can see it, just imagining it with the forces helps." Thus, he was aware that he needed to visualize the problem. An instance of evaluation occurred when the researcher asked him to reveal his responses on the new-knowledge activity. Aaron responded that, "…I wasn't thinking about anything else…" suggesting that he was aware of his cognitive limitation at that point. A second instance of evaluation surfaced when the researcher asked Aaron about how his conception agreed with that of the scientific community. Aaron's response was that, "I think that I'm pretty much correct; I might be missing a force or two, but with the air resistance and gravity I think I'm pretty much correct." A single instance that demonstrated both regulation and reflection occurred when Aaron confronted his misconception during the administration of the discrepant event. His initial understanding was that the Atwood Pulley would self-level if it supported equal masses. However, Aaron discovered the error of his understanding. He indicated that, "well, I guess a balance like that, would balance themselves out if they're the same weight."

Interestingly, Aaron demonstrated dissatisfaction with the prior conception at the end of the second phase when the researcher asked him about the level of difficulty of understanding the concept (see Table 2). He frustratingly responded that:

> *Mostly, I understood it better when it was put into a real case scenario like the golfer, or like baseball. It's kind of hard to understand something when I can't really see it in my head or relate it to something. If you're saying all this information I usually can't see it unless I see some type of diagram.*

Aaron seemed exasperated with the exercise while attempting to make the change.

When asked to quantify the perceived level of difficulty of understanding the concept, Aaron assigned a value of 2 out of 10 (see Table 5). He stated that the volume of class material made it difficult to fully comprehend this concept and that he better comprehended concepts when able to visualize them. He further stated that:

It's kind of hard to understand something when I can't really see it in my head or relate it to something. If you're saying all this information I usually can't see it unless I see some type of diagram.

His final statement was that:

I understood pretty nicely. Sometimes I get a little confused when you go so fast. I will eventually get it. I like to see things and I like to see diagrams. When you're talking about forces and you apply or you talk about the curve, I understand it better when I can see it. So, if you have displays or the Atwood machine, it makes my understanding better.

When asked to complete the posttest, Aaron selected the correct response to the question associated with the Hockey Puck misconception. Thus, Aaron successfully underwent conceptual change.

Phase I - Acknowledgment of Understanding - Benjamin

Benjamin was a 20-year-old White male majoring in construction management. His high school (GPA) was 2.6/4.0 and his college GPA was 2.4/4.0. He completed all previous math and science courses at the regular level with the exception of trigonometry, which he did not take at all. Benjamin's academic standing in Physics I course was 62% at the time of this writing. Benjamin's response to Question #9 of the FCI pretest was "b": "The downward force of gravity and the horizontal force of momentum in the direction of motion."

The researcher asked Benjamin to elaborate on his FCI answer for question #9:

Researcher: What I want to do is to talk about the pre-test that you took and a couple of answers that you provided. Let me read the question and I'll read the answer that you chose. The main force acting on a hockey puck after the puck has been kicked is…

Benjamin: I always assumed that gravity was a downward force….I thought that you said that it wasn't a downward, or something like that. But, uh, the momentum of the hockey stick…

Researcher: What is momentum? The puck is already in motion…

Benjamin: Could you repeat the question one more time?

Researcher: The diagram depicts a hockey puck in motion and it experiences a kick in constant motion.

Benjamin: Already in motion.

Researcher: It's already in motion in one direction. And in the other direction there's a force that cause momentum in the other direction. The question is that the main forces acting on this hockey puck after the kick are what….

Benjamin: After it's come into contact with the stick…

Researcher: Yes, after it's come into contact with the stick and going in that direction (the horizontal direction) then there's a force that's going to kick it that way (pointing a 90 degree direction).

Benjamin: It was worded a little confusingly. The way that I picture it happening in my head is why I came to that conclusion. I may have just been thinking about something else….

Benjamin did not seem to remember what he believed.

Phase II - Collecting Evidence

The researcher asked Benjamin to consider the Atwood Pulley and to predict the motion of the pulley, first with equal masses suspended, then with unequal masses suspended:

Researcher: Well right now, two conditions: one in which these two masses are equal and the other in which these two masses are not equal. So, the first question that we're going to ask is when these two masses are equal, is there a net force acting on the system? The other question is when these two masses are not equal, is there a net force acting on the system? I want to you make a prediction …

Benjamin: If the masses are the same… the acceleration is zero and there is a net force. If the masses are not the same… there is acceleration and the net force is not zero.

Benjamin's prediction contained the misconception that equal masses as well as unequal masses supported by the Atwood Pulley resulted in a net force. Benjamin's observation of the discrepant event is as follows:

Researcher: So, then what's your observation about when mass one and mass two are equal.

Benjamin: There's no net force and the acceleration equals zero.

Researcher: Now, when I add these paper clips, do you think that that will add mass to one of the hangers?

Benjamin: Honestly, nothing

Researcher: What's happening?

Benjamin: There's an acceleration and net force.

Benjamin discovered that unequal forces created an acceleration. The researcher asked Benjamin to elaborate on his findings:

Researcher: So, when these two are not equal what did you observe?

Benjamin: There's acceleration and a net force.

Researcher: Tell me about what you found out with this set up.

Benjamin: Well, I was misconstrued because I was off a little, but being that it's…..m_1 and m_2 are constant equal because they equal each other, but they don't necessarily have to be at the same position.

Researcher: So then, when the two masses are the same, what does that say about the net force and acceleration?

Benjamin: There's no acceleration and net force.

Researcher: Ok, and when m_1 and m_2 are not equal, what does that say about net force and acceleration?

Benjamin: There will be a net force and acceleration

When asked about the result of two equal masses suspended by the Atwood Pulley, Benjamin correctly responded that, "there's no net force, because they're equal," thus he realized that "no net force" resulted in "no acceleration." However, when asked to predict the result of adding mass to one side, Benjamin incorrectly stated, "Honestly, nothing." When he observed the event, he stated that:

> *There's an acceleration and a net force… Well, I was misconstrued because I was off a little, but being that it's…..m_1 and m_2 are constant equal because they equal each other, but they don't necessarily have to be at the same position.*

Thus, Benjamin realized that this prediction was partially inconsistent with the reality of the event.

The researcher asked, "…so then, when the two masses are the same, what does that say about the net force and acceleration?" Benjamin responded, "There's no acceleration and net force." The researcher followed up by asking, "…when m_1 and m_2 are not equal, what does that say about net force and acceleration?" Again, Benjamin responded that, "…There will be a net force and acceleration."

The researcher returned to the original question regarding the hockey puck:

Researcher: Go back to the hockey puck. The hockey puck is moving. After you kick something what is the acceleration after you kick it?

Benjamin: Uh…….

Benjamin was still unclear about concept. The researcher utilized the "pushing the car" example to discuss the relationship between net positive force and net positive acceleration. The researcher asked Benjamin to imagine standing behind a car that you are pushing and posed the question, "…after you push the car and remove your hands from the car, is the car going to continue to accelerate?"

Researcher: Imaging your car standing on the road. You're going to push the car. After you push the car and remove your hands from the car, is the car going to continue to accelerate?

Benjamin: No.

Researcher: You get behind your car, which way is the acceleration relative to your body.

Benjamin: Away from the car.

Researcher: What's going to happen to the acceleration when you remove your hand from the car. Will it continue to increase in velocity?

Benjamin: No. The car is going to stop after you remove your hands from the car.

Researcher: It's going to decrease until it stops

Benjamin: Right.

Researcher: So, when it' s decreasing relative to your body, is the acceleration positive or negative?

Benjamin: It's negative.

Researcher: And once you have pushed it and taken your hand away, is there a net force directed in that way away from you?

Benjamin: After you have released it.

Researcher: Released it…..after you have pushed the car and you have released it what will the car do?

Benjamin: It will stop.

Researcher: After you have taken your hand from the car the car will not continue to accelerate.

Benjamin: Right.

Researcher: So, it's going to do what?

Benjamin: It's going to decelerate.

Researcher: Decelerate. So, is there a force acting on that car directed away from you once you take your hands away?

Benjamin: No, it's acting toward the car which would be acting toward you.

The researcher then asked Benjamin to determine if the car would continue to accelerate after removing the push from the car. He indicated that the car would decrease in velocity until it stopped. The researcher sought to utilize the next series of questions to get Benjamin to accept the notion of net force resulting in acceleration. The researcher asked Benjamin to determine the direction of the net force once his hand was removed from the back of the car. Benjamin indicated that the direction of the net force was directed rearward.

Finally, the researcher again focused on the hockey puck:

Researcher: Ok, so the puck is moving and you kick it. It's going to do what it's going to do. It's not a continuous kick, you just kick it instantaneously.

Benjamin: …as soon as you kick it, it leaves your foot?

Researcher: Is the force still acting on the hockey puck.

Benjamin: No.

Researcher: So, what have you learned?

Benjamin: After the force has been applied, that the acceleration is zero and the net force is zero.

Researcher: That's what I wanted you to see.

Benjamin started with four misconceptions. His misconceptions were: (a) he embraced the impetus force; (b) Benjamin poorly understood the net force relationship to acceleration; (c) he identified momentum as a force; and (d) Benjamin did not believe that gravity generated a force (see Table 4).

Phase III - The New Knowledge Activity

After formally studying Newton's Laws in class, Benjamin participated in a second phase that focused on Benjamin's notion of force:

Researcher: Let's talk about your idea of force.

Benjamin: Force is an action acting on another body.

Researcher: And how do you determine force?

Benjamin: With….how do you determine it…

Researcher: If I were to ask you to calculate force, how would you do it?

Benjamin: The mass times gravity.

Researcher: Well, mass times acceleration, gravity being acceleration. And what about the units of force.

Benjamin: Newtons.

Researcher: Tell me what mass is.

Benjamin: Mass is the actual…..displacement…..I don't know what the definition of mass.

Researcher: The amount of material.

Benjamin: Oh yeah, the amount of material.

Researcher: And tell me what acceleration is.

Benjamin: Acceleration is the change in motion over the change in time.

Researcher: Change in velocity over the change in time.

Benjamin: Yeah.

Researcher: What is required to produce a force? We said that force is mass times acceleration.

Benjamin: An action with a change in velocity. Or an action with an acceleration.

Researcher: So, acceleration is required. So, if you have no acceleration, do you have a force?

Benjamin: No (doubtfully).

He correctly indicated that, "force was an action on another body." He further indicated that force was comprised of mass and acceleration. The researcher asked him to define mass. Benjamin incorrectly responded that, "…Mass is the actual…displacement." He finally admitted that, "I don't know what the definition of mass."

The conversation returned toward that of the hockey puck:

Researcher: Let's look at this example that we have here. Let's look at the hockey puck example...

Benjamin: Yeah.

Researcher: We said that the hockey that's moving along and it's going to be struck by a stick. It was going to cause it to along in some direction. One of the questions that we focused on was does that force continue on with the hockey puck while it's in it's motion. And most people thought that it did. And do you remember what you found out.

Benjamin: Yeah, it didn't. After the hockey hits it there's no more...well, there's the normal and the gravitational force.

Researcher: What about the force that hit it. Do you remember why that force is not there?

Benjamin: Yeah, because after it stops accelerating as soon as the hockey puck leaves the stick.

Benjamin correctly indicated that the force exerted on the hockey puck ceased after contact with the hockey puck.

The researcher turned to the New Knowledge Activity associated with the new context:

Researcher: Let’s look at that example there, position number one, the golf ball sitting on the tee. What are the forces acting at that point? What forces can you identify, do you see at that point?

Benjamin: So the golf club in the positive x direction and gravity, I wasn’t sure I guess just at the moment of impact, the gravity is going to be acting in the downward, the negative y and the normal in the negative x, and the positive y.

Researcher: Normal in which direction………..

Benjamin: The normal is in the positive y.

Researcher: The normal points in which direction.

Benjamin: Up.

Researcher: So you have the normal which is pointing up, the mg which is pointing which way…

Benjamin: ….down……

Researcher: ……and then the force of the stick on the ball, in which direction……

Benjamin: …..force of the stick on the ball in the positive x.

Researcher: Let’s look at the second position. What are the forces acting there?

Benjamin: Uh…gravity in the negative y, I went ahead and included wind resistance in the negative x, and that’s it.

Researcher: What are they………

Benjamin: gravity in the negative y, wind resistance.

Researcher: Is gravity a force.

Benjamin: Yes….

Researcher: What's required to produce a force.

Benjamin: Acceleration and mass, so no it's not.

Researcher: So what is gravity, then?

Benjamin: An acceleration.

Researcher: Acceleration, so it's not a force.

Benjamin: That's it?

Researcher: So, tell me again the forces that are in number 2.

Benjamin: Wind resistance, and …

Researcher: What all is acting down…

Benjamin: ……the weight.

Researcher: …..ok, the weight.

Benjamin: Ah yes, I guess that's what I meant to put. The weight is the mass times the gravity.

Researcher: What about three.

Benjamin: Should be the weight, but I put gravity…

Researcher: …..and anything else.

Benjamin: number three where it's at its maximum height. Still wind resistance…

Researcher: What about four?

Benjamin: After it came to rest, weight and normal, well I put gravity but I know better….I knew better than that, I just wasn't thinking.

Benjamin correctly identified the forces acting on the initial golf ball: the normal force and the weight force (see Appendix I). He said that the force from the stick acted on the ball in the direction of the ball's motion to get the ball in motion. However, he also indicated that the force on the ball from the stick dissipated immediately after the stick struck the ball. Benjamin correctly identified the remainder of the forces acting on the ball through its trajectory.

The researcher asked Benjamin to summarize his conceptions. He responded:

Force involves and mass and acceleration....the unit of force is the Newton...once a force acts upon a body and the body is in free motion , it's no longer acceleration unless there's friction involved, then it decelerates.

The researcher further asked Benjamin to describe what he had learned. He said, "After the force has been applied the acceleration is zero and the net force is zero."

Phase IV - Conceptual Change Strategies

Benjamin believed that the hockey stick created a "force" of momentum that continued with the hockey puck. The discrepant event altered his conception causing him to believe that, "after the force has been applied that the acceleration is zero and the net force is zero." Thus, his conception was now partially consistent with that of the scientific community – partially because the object in motion experienced friction. Consequently, the net force was not zero, but was negative, which created a deceleration. The second phase revealed his ideas about the conception. Benjamin stated that, "after the hockey puck hits it there's no more…well, there's the normal and the gravitational force." At this point Benjamin accepted this conception as intelligible and plausible. Benjamin's example of this concept involved the use of a conveyor belt that moved rocks from a rock quarry five miles away. The awe with which Benjamin spoke about this example revealed his ideas in the value (fruitfulness) of the conception (see Table 2).

With the new-knowledge activity, Benjamin correctly identified the forces acting on the golf ball that was at rest: the normal force and the weight force. The researcher asked Benjamin to summarize his conceptions. He responded:

> *Force involves and mass and acceleration....the unit of force is the Newton...once a force acts upon a body and the body is in free motion , it's no longer acceleration unless there's friction involved, then it decelerates…after the force has been applied the acceleration is zero and the net force is zero.*

An additional example that he chose to share involved the hitting of a golf ball. He again, correctly identified the forces acting on the ball during its trajectory, thereby seeming to demonstrate fruitfulness of the new concept (see Table 3). However, he did not choose the correct posttest response.

Benjamin revealed instances of metacognitive awareness of his progress and limitations of learning:

> *It was worded a little confusingly. The way that I picture it happening in my head is why I came to that conclusion. I may have been just thinking about something else…*

Here, Benjamin referenced his awareness of a learning error that he attributed to his personal learning strategy – formulating visions that, in this case, lead him to error.

This same statement revealed Benjamin’s use of evaluation as a conceptual change strategy. He stated that he was thinking about something else, which was a demonstration of judgment of his thinking capacities and limitations. Further, Benjamin stated that, “I was misconstrued because I was off a little” which was a demonstration of regulation – during this time he altered an answer regarding the effect of unequal masses on the system’s acceleration (see Table 5). Benjamin utilized reflection when he determined that his thinking was incorrect in his account of the force acting on the hockey puck. He stated that:

> *After the force has been applied that the acceleration is zero and the net force is zero.*

Benjamin, who experienced conceptual change, attributed his lack of understanding the concept to his poor memory. He quantified his level of difficulty in understanding the concept as 3 out of 10. He stated that he took physics in high school, completed regular physics in high school and graduated with a high school GPA of 2.06/4.00. The researcher asked Benjamin to describe his struggle with understanding the concept. He responded that, “Vectors and the multitude of different equations, and I get lost.” Thus, the volume of work in the class caused him problems.

When asked to complete the posttest, Benjamin selected the correct response to the question associated with the Hockey Puck misconception. Thus, Benjamin successfully underwent conceptual change.

Phase I - Acknowledgment of Understanding – Caleb

Caleb was a 26-year-old White male pursuing a bachelor's degree in computer science. He did not provide a high school GPA, but indicated that his college GPA was 3.9/4.0. Caleb indicated that previous courses taken were Algebra I and II, geometry, trigonometry, and calculus, all at the regular level. Caleb's academic standing in Physics I as of this writing was 64%. Caleb chose selection "b" for Question #9 on the FCI: the downward force of gravity, and the horizontal force of momentum.

During the first phase, the researcher asked Caleb to elaborate on his FCI response related to the forces acting on the hockey puck:

Researcher: One of the question that showed up on the pretest was this….the main forces acting on a hockey puck after it's been kicked are….and it asked you to identify the forces. And the forces that you identified were these: the downward force of gravity, the horizontal force of momentum in the direction of motion….

Caleb: That was my answer?

Researcher: Yes. Tell me what you think about that. You have a hockey puck moving and gets hit. What are the forces, and the puck is on the ground on ice and gets hit with a stick. So, in your estimation, what are the forces acting on the hockey puck after it gets hit.

Caleb: The friction on the ice, I don't know how to describe it, but I mean, it will, maybe that's it. The friction on the ice will slow it down. I don't know if there is wind or something like that, but maybe with something like, maybe there's something with pressure. Or if gravity is pushing down on the puck would slow it down.

Researcher: Do you think that gravity is acting on it.

Caleb: Yeah, it would have to because gravity acts on everything.

Researcher: What about the force that created the hit? What happens to that force?

Caleb: It's, I guess, a some energy is created when it's hit and it gradually loose its power as time went on. So, I guess, when you said after the hit, I just said, I don't know.

Researcher: So, you believe then, that a hockey puck is traveling on ice that has been hit by a hockey stick, the forces acting on it are friction, and what did you say about gravity.

Caleb: Gravity is pushing it down, so that might cause it to slow.

Researcher: And then you think that, say it again about the force of the stick.

Caleb: The hit, when it hits, it would generate some sort of energy, momentum, into the puck. I guess it would lessen over time.

Caleb correctly believed that friction decreased the velocity; however, he also believed that the force on the hockey puck that created the positive velocity generated energy and that the force "lessened" over time. With this response, Caleb demonstrated the lack of a concise conception related to the question.

Caleb believed that the impulse continued with the object as it moved along its kinematic path. This response further pointed to Caleb's misunderstanding of the conservation of energy, believing that energy was created to produce the motion.

The researcher probed Caleb's conception of net force:

Researcher: Now, let's talk about the concept of net force...What is your idea of force?

Caleb: Uh, force, when I think about force I think of how hard I push on something or how hard something is pushing on me or directed energy.

Researcher: What results from a force?

Caleb: Movement….

Researcher: Ok, um, what is your idea of mass?

Caleb: The composition, how dense something is, weight….

Researcher: Now, so your idea of force is a push or a pull…

Caleb: Yeah….

Researcher: And that's correct. It's a push or a pull. Now if I'm standing and I have a pull in one direction and a pull in the other direction, what would happen if the pull in my right direction is greater than the pull in the left direction?

Caleb: It would move to the right.

Caleb correctly defined force as, "how hard I push on something or how hard something is pushing on me or directed energy." Further, his incorrect idea of mass was, "how dense something is, [or] weight." He did not realize that mass and weight are distinct.

Phase II - Collecting Evidence

The researcher asked Caleb to prediction the behavior of the Atwood Pulley with equal masses suspended from each string and with unequal masses suspended from each string:

Researcher: Ok, let's look at this set up here (see Figure 1). Right now, I'm going to set this up so that the mass of one side is equal to the mass on the other side. I want you to predict what's going to happen if those two masses are the same. Then I want you to predict what would happen if the two masses are not the same. I want you to write those predictions on that sheet (explaining the discrepant event sheet)…

Caleb: The way that this is set up, it is likely now set up for the second part of the last experiment for the last person that you interviewed. It seems to have more paperclips on one side that the other side. That sort of influenced my decision. Not that…I would have guessed it anyway…..that just made me feel better about my decision.

Researcher: Ok, you're thinking that when the two masses are equal, what should happen?

Caleb: They should be the same…this is a weight thing…and the one with the greater mass, the one with the greater mass would pull it down.

Researcher: So, it's your contention that when the masses are equal, they should be at the same level.

Caleb: Yes.

Researcher: And when they're not, then they should be at different levels.

Caleb: Yes, if my understanding is synonymous with weight, and if those terms are interchangeable, then I don't know what I'm talking about.

Caleb predicted that equal masses on the Atwood pulley would result in leveled masses; he further predicted that, "the object with greater mass will be lower" among the unequal masses. Upon observing the Atwood Pulley with equal masses that did not self-level, Caleb realized his error but did not understand why.

The researcher allowed Caleb time to experiment on his own. During this time, Caleb moved the suspended weights up and down, discovering that when left to themselves, they did not self-level. Thus, Caleb came to the correct conclusion that the self-leveling misconception was incorrect:

Caleb: I still don't understand why if the masses were equal, why it didn't level out. Because I would think that, I guess I don't understand the pulley system. Because, equal weight here, and equal weigh here, there's no reason for it to move. But, it just seems like there would be. But, I sort of get the impression of equal weight-equal weight, there would be no reason to move. But, it just looks like it should.

Researcher: You're thinking of a scale…..The difference between a scale is that a scale has a mechanism that has two bars that create a system to create that which you're talking.

Caleb: I think that's where I got mixed up. The more I sit here and think about it, the more equal mass has no reason to move.

The researcher followed up by asking Caleb to describe the acceleration resulting from equal masses:

Researcher: So, in terms of acceleration, when two masses are the same, is there any acceleration?

Caleb: No

Researcher: And when the two masses are not the same is there any acceleration.

Caleb: Yes

Researcher: Now let's go back and talk about….in your idea, if this is not accelerating, that would then suggest that the relationship between $mass_1$ and $mass_2$ is what?

Caleb: Equal.

Researcher: They are equal. What do you think the net force is on the system if that mass and that mass are the same?

Caleb: Zero.

Researcher: So, then you could turn that around and say that if the net force is zero, is there any acceleration?

Caleb: No.

Finally, the researcher asked Caleb to reconsider the hockey puck example. The researcher asked if the hockey puck was accelerating along the ice after the stick has hit the puck. Caleb indicated that the puck would decelerate:

Researcher: Think back about the hockey puck. The puck is moving along ice. While the thing is in contact with the stick, is the hockey puck accelerating?

Caleb: Yes.

Researcher: When the stick is taken away from the puck is the puck going to accelerate or decelerate?

Caleb: I going to have to guess decelerate.

Researcher: Decelerate. So then, after the puck has been hit with the stick what happens to the force?

Caleb: It…..gets smaller and smaller, less and less or completely gone, and at that point you're dealing with the after effect of the force.

Caleb still incorrectly contended that the force from the stick gradually diminished until the puck came to rest. The researcher moved to the example associated with the "pushed car":

Researcher: Let's say that your car is sitting a horizontal force. You're going to push the car; while pushing, what's going to happen to the velocity?

Caleb: It's going to increase

Researcher: Alright, acceleration. After you remove your hands from the car what happens to the acceleration – is the velocity going to increase, decrease or remain the same?

Caleb: Decrease.

Researcher: So, then if there is no force acting on the car is there an acceleration. So, with the hockey puck there's no force acting on the hockey puck is there an acceleration.

Caleb: No.

When asked about the acceleration of a "pushed" car, Caleb correctly stated that the car accelerated while being pushed and that the car decelerated after the "push" was removed. The researcher attempted to connect this example to that of the hockey puck by stating:

Researcher: So when you take your stick away from the hockey puck is it going to accelerate or decelerate.

Caleb: Decelerate.

Researcher: Is there a force.

Caleb: No (laughing)….

Researcher: Thus, after you hit the puck with the stick, what happens to the force?

Caleb: That's the question. I have no idea what happens to the force.

Researcher: Is there a force?

Caleb: After you hit it, I'm guessing no.

Researcher: That's the answer………….

Caleb realized that the force exerted by the hockey stick ended after it struck the hockey puck.

Caleb brought the following misconceptions to the research investigation that needed to be confronted: (a) Caleb believed, not only in the impetus force, but that the impetus force diminished over time; (b) he believed that equal masses suspended from the Atwood Pulley self-leveled; and (c) Caleb believed that force created movement rather than acceleration (see Table 4).

Phase III - The New Knowledge Activity

The second phase of the investigation, which commenced after a formal study of Newton's Laws, began with a discussion of Caleb's understanding of force, mass and weight:

Researcher: Let's talk about your conception of force. Describe force for me.

Caleb: Force is mass times acceleration.

Researcher: Good. What are the units of force.

Caleb: Newtons.

Researcher: What is mass?

Caleb: Mass is weight.

Researcher: ….what……

Caleb: ….weight….no, weight is mass and gravity, right so mass is acceleration divided by force.

Researcher: That's one way of looking at it. Fundamentally, it's the amount of material. What about acceleration.

Caleb: The change in velocity over time.

Caleb correctly defined force and acceleration. However, he incorrectly defined mass as being equivalent to weight.

When again discussing the hockey puck misconception the researcher asked Caleb to determine if the puck was accelerating or decelerating after being hit:

Researcher: Let's review the hockey puck that is sitting still and you're going to hit it with a stick. During the time it's being struck what are the forces acting on the hockey puck while it's being struck.

Caleb: I don't remember what we talked about. But I assumed, the weight, the mass of gravity down, normal force pushing up, force of the stick hitting the puck. Those are the three that I got.

Researcher: What about friction. Do you think that friction's there at all.

Caleb: If it's not moving, I mean if it's actually moving then there would be friction. But as it sits, it's as if there's friction with an object that doesn't move. And if friction doesn't exist until it's actually going against it. I guess there would have to be friction.

The researcher reviewed Caleb's understanding of the concept related to the hockey puck (see Figure 1):

Researcher: Let's review the hockey puck that is sitting still and you're going to hit it with a stick. During the time it's being struck, what are the forces acting on the hockey puck while it's being struck.

Caleb: I don't remember what we talked about. But I assumed, the weight, the mass of gravity down, normal force pushing up, force of the stick hitting the puck. Those are the three that I got.

Caleb maintained that the force of the stick continued with the puck through its trajectory.

The researcher asked Caleb to complete the New Knowledge exercise:

Researcher: Let's look at that example here. You have four different instances. What are the forces acting on the golf ball?

Caleb: I've written down normal force, gravitational, uh weight, the impact of the club and now friction of the ball on the tee.

Researcher: What did we talk about in class that would fit this problem?

Caleb: We talked about impulse and momentum (thinking)……..

Researcher: Let's look at the number two point. What are the forces acting there?

Caleb: I put weight, and air resistance.

Researcher: What about the force of the stick on the ball. Is it still there?

Caleb: No.

Researcher: Why?

Caleb: Because it’s only there when they’re touching and after that it’s decelerating the rest of the way.

Researcher: Do you think that ball at number 2 is accelerating in the x direction?

Caleb: No.

Researcher: Well we made the assumption in class that. The assumption made was that there was not acceleration. But in reality, what do you think would happen in reality?

Caleb: Um, from my understanding about what we talked about it’s going to be accelerating the fastest at the moment it leaves the club and decelerating the rest of the way.

Researcher: That’s correct. Let’s look at number three.

Caleb: I got the same weight and air resistance.

Researcher: And what about at number four?

Caleb: I have the normal force, the weight, and then there would be friction as well.

Caleb correctly answered all the “new knowledge” questions (see Appendix I). The researcher asked Caleb to elaborate on his current understanding:

Researcher: I think that with your first interview that when something was in free-fall motion what ever force set it in free fall motion continued with the object. Was that your prior understanding?

Caleb: Yes.

Researcher: Is that still your understanding.

Caleb: No.

Researcher: What is your current understanding?

Caleb: That force is applied to the object at the point of impact and from then on out there's no force because the object itself is accelerating, it's slowly decelerating and the time is increasing from the time.

When the researcher asked Caleb to elaborate on his understanding of the new knowledge activity relative to the concept, Caleb responded, "…it's [the force] only there when they're touching and after that it's decelerating the rest of the way."

Caleb seemed to have undergone conceptual change.

Phase IV - Conceptual Change Strategies

Caleb incorrectly identified the downward force of gravity and the horizontal force of momentum as the forces acting on a hockey puck through its trajectory. After the administration of the discrepant event Caleb indicated, "I have no idea what happens to the force….after you hit it, I'm guessing no [force]." Caleb began the process of conceptual change. However, he did not yet regard the new conception as intelligible (see Table 2). Caleb experienced intelligibility at the start of the second phase when he stated that, "force is applied to the object at the point of impact and from then on out there's no force because the object itself is accelerating, it's slowly decelerating and the time is increasing from the time." In addition, Caleb accepted this new conception as plausible. However, as a computer science major, Caleb did not appear to accept this new conception as valuable because of his computer science emphasis. Thus, when asked to provide an example in which this concept would be useful, Caleb struggled to provide such an example, finally stating that he could program a computer to make certain applications. This statement confirmed that the conception lacked fruitfulness for Caleb (see Table 2).

Caleb demonstrated the first instance of metacognitive awareness when he explained is frustration with the outcome of the discrepant event (see Table 3):

> *I still don't understand why if the masses were equal, why it didn't level out. Because I would think that, I guess I don't understand the pulley system. Because, equal weight here, and equal weigh here, there's no reason for it to move. But, it just seems like there would be. But, I sort of get the impression of equal weight-equal weight, there would be no reason to move. But, it just looks like it should. You're thinking of a scale…*

In the other instance Caleb stated that"

> *It seems to get a bit confusing in that respect. It's not an equation that you just plug in values to like the first stuff. You had kinetic formulas. You get these values, you get the equation and plug in the values and solve for the unknown. Now you solve for the variable, take the variable and apply it to the other. That's what gets challenging.*

Caleb utilized metacognitive evaluation when he discussed the discrepant event with the researcher:

> *…if my understanding is synonymous with weight, and if those terms are interchangeable, then I don't know what I'm talking about…*

After the discussion of the discrepant event, Caleb articulated his understanding and observation. He indicated that:

...if these are supposed to have the same mass, I would have assumed they would have been even, but this is showing that they're not. One is decidedly lower than the other…

Caleb modified his thinking, thus revealing the use of the metacognitive strategy of regulation. There were no instances of reflection.

Caleb quantified his level of difficulty in understanding the concept at 5 out of 10 (see Table 5). He stated that:

Maybe all of the ways the equations interact. Force is ma [the product of mass and acceleration], so then if another equation is using force, "ma" would substitute into that equation and that kind of stuff. The problem was I was telling you that I missed with the tensions, you had the 2 tensions to figure out and knowing that the tension in the y direction was going to equal zero and so you could solve it for that tension and then solve it back into the other one. The sort of intermingling of all the equations and trying to figure out how to get a variable value so that I could get into the other equation. It seems to get a bit confusing in that respect. It's not an equation that you just plug in values to like the first stuff. You had kinetic formulas. You get these values, you get the equation and plug in the values and solve for the unknown. Now you solve for the variable, take the variable and apply it to the other. That's what gets challenging.

Caleb's struggle with the concept was rooted in his perception that the mathematical equations confused him.

When asked to complete the posttest, Caleb selected the correct response to the question associated with the Hockey Puck misconception. Thus, Caleb successfully underwent conceptual change.

Phase I - Acknowledgment of Understanding – Doug

Doug was a 34-year-old White male pursuing a Post- Baccalaureate degree in biotechnology. Doug came to this institution as a non-traditional student with a 3.4/4.0 GPA and has earned a 3.0/4.0 college GPA. He enrolled in all regular high school math and science classes. At the time of this writing, Doug's academic standing in Physics I was 80%. Doug selected response "c" to question #9 on the FCI: The downward force of gravity, the upward force exerted by the table, and horizontal force acting on the puck in the direction of motion.

The first phase began with asking Doug to explain his reasoning for his response to FCI question #9:

Researcher: Let's talk about a hockey puck that may be moving along the ice. The main forces acting on a puck after you kick it are….and the answers that you gave was the downward force of gravity, the upward force exerted by the table and the horizontal force acting on the puck in the direction of motion. Explain to me how you came up with those answers.

Doug: Um, well you know that gravity effects every thing and it has an effect on the hockey puck; you know that there is friction and there is always the force that the force acts on the puck from the table. That's how I came up with those answers.

Researcher: Ok, what about the force…one of the forces listed here is…after the hockey puck is placed in motion there's a horizontal force acting on it. There's the downward force of gravity, the upward force of the table and the horizontal force acting on the puck in the direction of motion and friction. If you're looking down on the table, it's moving in this direction. Talk about the horizontal force

Doug: Well that comes from that kick…. I mean it would continuously…..it's hard for me to determine for me right now the angle it would have but this motion is from this force..

Researcher: So do you think that there really is a force acting here and…..talk about this force……let's say that this force is at rest and we hit it. It's going to accelerate. What happens to the net force? Does it end, does it continue?

Doug: I would think that it continues…

Researcher: It would continue after it hits? What about the force of the surface on the puck. Is there a force on it. Talk about that.

Doug: After you kick it there's still a force on it.

Doug correctly indicated that gravity affected everything and that an always-present friction is a force on the puck.

When asked to explain his understanding of the horizontal force acting on the hockey puck in the direction of travel, he said that:

> *Well, that comes from that kick...I mean it would continuously…it's hard for me to determine for me right now the angle it would have but this motion is from this force.*

The researcher's follow up question asked, "…do you think that there really is a force acting here…" Doug responded that, "I would think that it continues….after you kick it there's still a force on it." Doug believed that the force on the hockey puck continued after the kick.

Phase II - Collecting Evidence

During the discrepant event, the researcher asked Doug to identify the forces acting on a marble sitting at rest on a desk. The researcher utilized the "marble" discrepant event rather than the Atwood Pulley because Doug was the first student to participate in the phase. The researcher determined that this example did not work well and thus changed all subsequent examples to the Atwood Pulley.

Researcher: I have this set up here. What we're going to do is to talk about the force. The finger will represent the force. We'll discuss the normal force and the marble when it's in motion. So, your idea is that after the marble is in motion the force continues. And you also contend that there is a force on the surface on the after it's in motion…. Now, what is the role of your finger?

Doug: Producing a force against the marble.

Researcher: Once the marble begins to accelerate what happens to the force.

Doug: Well, my force stops once it accelerates the marble.

Researcher: Go ahead and accelerate the marble. Does your finger acting as the force continue as this thing is moving?

Doug: The force that I placed upon it does, but my, I don't if you separate those two; but my finger is no longer touching but my finger's force is still having an effect on it. Does that make sense? I don't know if I'm saying that right.

Researcher: What is your finger doing?

Doug: It's producing a force.

Researcher: Now, my question is what happens to the force, not the effect of the force, but the actual force. What happens to the force after you have removed your hand from that marble. Your finger is producing a force, right.

Doug: I'm no longer producing the force.

Researcher: But the ball continues. So, what I'm trying to get to is what happened to the force.

Doug: It went away, but it's still applied, I mean, it's still with it, cause my finger was the force and it's still moving as a result of that force. So, that force, um, is still having an effect with that ball. It's still producing a certain amount of Newtons. It's still being affected by it. I don't know it that's right; I mean that ball is, that force is still on that ball cause it's still moving. Even though my finger is back here, that force is still being applied. And I want you ask you if that's correct.

Researcher: How could the force still be applied if your finger is there and the ball is there?

Doug: Cause of what I did to it because I produced enough force for it to leave my finger and start rolling. So, the force that I exerted on is still is still in effect. It causes that ball to move.

Researcher: So if there is a force is there an acceleration. If the acceleration goes to zero………

Doug: Force is mass times acceleration. Mass times zero…..you have zero acceleration then I guess the force is going to be zero. So, when I think about the equation then my prediction is wrong. Because if the acceleration goes to zero, then anything times zero is zero. Then that means that the force is zero. But, I don't know if I'm thinking about it too mathematically. I have changed my theory to where I'm thinking.

Researcher: What if you pushed that marble with your hand and it begins to slow down. Is that a positive acceleration?

Doug: It's negative.

Researcher: If the ball is moving away from but it's slowing down what is the direction of the acceleration?

Doug: If the acceleration is still going away…..

Researcher: The ball is still moving away from you, just imagine that you're standing behind a car. The car accelerates. Which way is the vector direction of the acceleration.

Doug: It's slowing down but it's still….I guess it would still be forward but I guess it's coming back

Doug correctly stated that, "…the normal force and weight forces are the forces acting on the marble." The researcher asked Doug to accelerate the marble with the use of his hand, which he did and to characterize the role of his hand in the acceleration of the marble. Doug stated that, "… the role of my hand was to produce a force, which resulted in acceleration." The researcher pursued the next line of questioning which considered the acceleration of the marble after being hit. The researcher asked, "…did the marble continue to accelerate or decelerate after being hit with the force of the hand and what happened to the force?" Doug responded that:

> *…it [the force] went away, but it's still applied, I mean, it's still with it, cause my finger was the force and it's still moving as a result of that force. So, that force, um, is still having an effect with that ball. It's still producing a certain amount of Newtons. It's still being affected by it. I don't know it that's right; I mean that ball is, that force is still on that ball cause it's still moving. Even though my finger is back here, that force is still being applied.*

Doug still struggled with the notion that the force ended after being in contact with object.

The next strategy employed by the researcher was to set the context of the discussion with the pushing of a car; the researcher asked about the relationship between exerting a pushing force against the back of a car and the resulting acceleration:

Researcher: Let's say this……..your wife is sitting in the car…..and she goes down an incline. I'm standing at the top of the incline and you're standing in front of the car. You're trying to slow down the car. You're pushing back toward me up the hill. So, which way is the force.

Doug: The force is away from me toward you and toward her.

Researcher: Right, toward me because you're trying to do what to the velocity.

Doug: I'm trying to slow down that velocity.

Researcher: Which way is the acceleration and the force?

Doug: The acceleration is toward you.

Researcher: Correct, if you take that ball that is rolling away from and it's beginning to slow down, which way is the acceleration.

Doug: (pondering)

Researcher: …and you slow it down, what way is the acceleration.

Doug: That acceleration is toward me and the force is toward me. Now, it makes sense.

Researcher: So the force is in your direction.

Doug: Right.

Doug correctly understood that pushing a car from rest would result in a positive acceleration and that creating a negative velocity resulted from a negative force. He began moving toward the understanding that removing the force would result in a negative acceleration.

The researcher asked Doug to describe the force that accelerates a car. He correctly identified the engine as the source of the force. Doug was asked to explain what happens when the driver removes his foot from the accelerator. Doug, again, correctly asserted that the car decelerates; the researcher asks if the force in that circumstance continued in the direction of motion. Doug said:

> *When you say that, then no. Because I'm not pushing the gas to accelerate, but it's still moving. And I don't know whether force has an influence on motion or not. Force is mass time acceleration. So, inertia is a force. If it's on level ground, it will continue to move forever. Friction will cause it to slow down.*

Doug's final comment was:

> *When it's accelerating in a positive direction or a positive acceleration there is a force. When it's at constant speed, there is no force. And then when it has a negative acceleration there is a negative force, friction.*

Doug's initial conceptions contained four misunderstandings. The misconceptions were: (a) that he supported the impetus force; (b) he equated acceleration and speed; and (c) Doug believed that inertia was a force and believed that force created motion (see Table 4).

Phase III - The New Knowledge Activity

The second phase began with a discussion of Doug's idea of force. First, the researcher asked Doug to discuss his idea of force, mass and acceleration.

Researcher: Talk to me about force, your idea of force.

Doug: Uh, force is equal to mass times acceleration. It's outside; forces are things that act upon an object.

Researcher: What's mass?

Doug: What is mass? Mass is how much space something takes up.

Researcher: And what about acceleration?

Doug: It's a force.

Researcher: Acceleration.

Doug: It's how fast something is moving. Right?

Researcher: No, it's the change in velocity divided by what?

Doug: ….time….

Researcher: Right. So, it's the rate at which the velocity changes.

Doug: Right, change in velocity divided by time.

Doug correctly indicated that force was equal to the product of mass and acceleration; however, he further incorrectly indicated that mass was the amount of space taken up and that acceleration was how fast something was moving. Doug confused speed with acceleration. After probing his understanding, Doug correctly responded that acceleration was the change in velocity divided by time.

Researcher: Let's talk about that exercise that I gave you. I asked to identify the force.

Doug: On the first one the force being struck by the golf club. I put the force of the club hitting the ball, the normal force from the tee that it's exerting on the golf ball, gravity, friction of the golf ball sitting on the tee and then as soon as the ball is being hit, air resistance.

Researcher: And what about in the second one.

Doug: The only forces are air resistance and gravity.

Researcher: And third.

Doug: Just gravity. And fourth I put just gravity and the normal force that applies.

Researcher: Any air resistance on the third one.

Doug: Oh yeah, there should be air resistance. I thought I may have left it off.

Researcher: And what about the fourth one, the last one.

Doug: I just put down gravity and the normal force.

Doug correctly answered all questions on the activity (see Appendix I) used to assess his understanding of the new concept. He realized that a golf ball on a tee was subjected to the normal force and the weight force. He also realized that the force of the golf club on the ball did not continue along the trajectory:

> *I thought that it might continue on with it. But it ends. As soon as you hit it it ends, the force is over.*

Finally, he realized that the ball at rest was again subjected to only the normal force and the weight force.

The final conversation focused again on the hockey puck and the forces acting on it, especially after it experienced the impulse.

Researcher: Ok. Let’s talk about when you had your first phase and we talked about the hockey puck and one of the things, the question that I asked, you have this hockey puck going along and it gets struck by a hockey stick and it goes off in its direction. What about the force that strikes the puck. Does the force that strikes it end, continue.

Doug: I thought that it might continue on with it. But it ends. As soon as you hit it, it ends, the force is over.

Researcher: Do you have any idea of where it goes?

Doug: (thinking)……could it come back. No I don't have any idea.

Researcher: Describe the concept that we have talked about in your own words about acceleration and mass, what you understand it to be.

Doug: …….according to this example…..Um, well, you have several types of force. You have forces, an object sitting down on something is being pushed up…..there's opposite forces that are going along with that that I didn't realize before that are pushing up on something….everything is pushing against each other……um I knew about friction…..friction is a big force……but um let's see you have…..the normal force is the one that I didn't really think about before as we've done a lot of examples over in class.

Doug seemed convinced that the force ended.

Phase IV - Conceptual Change Strategies

Doug appeared to have embraced the new conception, thus demonstrating intelligibility. When asked to provide an example utilizing this concept, Doug chose to share an example related to playing golf. He realized that the force that he would use to strike a golf ball ended the moment the contact between the ball and club were broken. This example demonstrated fruitfulness, the value the concept exemplified with the student (see Table 2).

Doug utilized awareness as a conceptual change strategy twice during the investigation (see Table 3). First, the researcher asked him to explain the horizontal force creating the acceleration, to which he responded that, "…it's hard for me to determine for me right now the angle it would have but this motion is from this force…" Here, he realized his limited progress. Awareness also surfaced well into the second phase when the researcher asked Doug to explain where the force on the hockey puck disappeared to after striking the puck. He stated that, "…I knew about friction, but the normal force is the one that I didn't really think about before as we've done a lot of examples over in class." Doug utilized evaluation when discussing the outcome of the discrepant event. His explanation for the difference in prediction and outcome are as follows:

> *Force is mass times acceleration. Mass times zero…you have zero acceleration then I guess the force is going to be zero. So, when I think about the equation then my prediction is wrong. Because if the acceleration goes to zero, then anything times zero is zero. Then that means that the force is zero. But, I don't know if I'm thinking about it too mathematically. I have changed my theory to where I'm currently thinking.*

The previous statement also demonstrates the use of the reflection strategy, for Doug altered his course of action when he considered the outcome. There was no use of the regulation strategy. Doug's posttest score was unsatisfactory because he chose the incorrect response.

Doug did not experience conceptual change. He struggled with conceptualizing the vectors in the exercise. He quantified his level of difficulty in achieving an understanding at 5 out of 10 (see Table 5). He stated that:

> *You just have to think about how things are moving with different forces and how they are applied and, like I say, there's normal force which I have never thought*

about before and I ……just thinking about breaking these forces down into components that…and that's been the hardest part.

When asked to complete the posttest, Doug selected the incorrect response to the question associated with the Hockey Puck misconception. Thus, Doug did not successfully undergo conceptual change.

Phase I - Acknowledgment of Understanding – Edward

Edward was a 36 year old Hispanic male majoring in computer engineering technology. His high school GPA was 3.5/4.0; his college GPA was 2.2/4.0. He enrolled in regular level physical science, physics, Algebra I and II, geometry and trigonometry. As of this writing, Edward's academic standing in Physics I is 65%. Edward's chose selection "b" on question #9 on the FCI. That response stated that the forces acting on a hockey puck immediately after being struck by a stick were the downward force of gravity, the horizontal force of momentum in the direction of motion. The researcher asked Edward to explain is FCI response:

Researcher: With the pretest that I gave you….you have a hockey puck that's moving horizontally on ice. The hockey puck is going to receive it from a stick. The question asks you to identify the forces on the puck after it is hit. The question that you gave here was that the downward force of gravity was one, and the other one is the horizontal force of momentum in the direction of motion is the answer that you gave. Tell me why you came up with those answers, why you think that those answers were true.

Edward: Uh, the only thing that I can think is that I figure that momentum is affected by the friction although there is minimal friction on the ice. The hockey puck can only go so far when you kick it.

Researcher: What is momentum?

Edward: It's the, the motion that keeps it going and an object moving.

Researcher: Do you know if momentum has any direction related to it; is it a vector or is it a non-vector quantity.

Edward: I would say that it's a vector because it slows down so…I would say that it's a vector.

Researcher: So then, your idea is that when this hockey puck is kicked that momentum is going to carry it and that momentum is a force that's going to carry it.

Edward: Right.

Edward's justification for his FCI selection was:

> *The only thing that I can think is that I figure that momentum is affected by the friction although there is minimal friction on the ice. The hockey puck can only go so far when you kick it.*

When the researcher asked Edward to define momentum, he responded "…it's the motion that keeps it [the object] going and an object moving." The researcher then asked Edward if momentum was a vector quantity. He stated that, "…it's a vector because it slows down….I would say that it's a vector." The researcher then summarized Edward's statement: "So then your idea is that when this hockey puck is kicked that momentum is going to carry it and that momentum is a force that's going to carry it." Edward responded "right" to this question.

The researcher asked Edward to define force and mass:

Researcher: Let's talk about net force. First off, what is your idea of what mass is?

Edward: Mass is just the amount of what something's made of like a piece of block, you take the cube of the block and that's where your mass is. Mass….is directly related to, is indirectly related to weight. I'm not sure.

Researcher: What about force; what is your idea of what force is.

Edward: It's the energy used to move that object or to do work.

Researcher: And how is force and acceleration related?

Edward: The more force you put on an object the acceleration is increased, or vice versa; if you put it in the opposite direction then it will decrease, I mean the acceleration.

Researcher: You're talking about weight?

Edward: Weight as compared to acceleration.

Researcher: What's your idea of what weight is?

Edward: Weight is…..the pull of gravity times the mass. I'm not even sure about that.

Edward indicated that force was the energy used to move an object or to do work. He further indicated that mass was the amount of what something was made of. The researcher then asked Edward to explain his idea of the relationship of force and acceleration. He stated that, "…the more force you put on an object the acceleration is increased, and vice versa; if you put it in the opposite direction then it will decrease.

Phase II - Collecting Evidence

The discussion of the discrepant event began with the researcher asking Edward to predict the behavior of the Atwood Pulley supporting even masses:

Researcher: So, if I have a system set up and the system has masses on each and those masses on each side are the same, what's going to happen to the system; what's the system going to do?

Edward: It should just say even.

Researcher: What do you mean by even?

Edward: Well if you have 500 grams on one end and 500 grams on the other, it should be level; it should be at the same height.

Researcher: Are you saying that one side should be at the same height as the other or one side should be higher than the other side.

Edward: They should be at the same level.

Researcher: And what would happen if one mass was heavier than on the other side?

Edward: Then the heavier mass would start pulling down the lighter mass.

Researcher: And what results?

Edward: Acceleration.

Researcher: How are the differences in the two masses and the acceleration related? In other words, if I have one mass on one side than the other side, how will that affect acceleration?

Edward: How will that affect acceleration? You'll have greater acceleration.

Researcher: Let's look at this set up here. You said that if these two masses are the same that they should move like this.

Edward: If they were same mass at opposite ends, I think that in what ever position, they will stay, cause you have the same mass on either end.

Researcher: I want you to write your prediction where you see number one (explaining the discrepant event form)…So, your prediction is that when the two masses were equal what happened?

The researcher performed the experiment, allowing Edward to observe the outcome and to examine his prediction against the reality of the event:

Researcher: Ok, so I'm going to start this one and see what is going to happen. What do you think is going to happen?

Edward: I think it's going to stay there.

Researcher: (demonstrating)……ok your prediction is correct. Now, let's see what happens if you add some mass. Your idea is what.

Edward: If you add it to this one, this one should come down and the other one will go up.

Researcher: Is there an acceleration here.

Edward: Yes.

Researcher: How can you tell there's an acceleration?

Edward: One is pulling the other one; I can see it.

Researcher: Well, what is acceleration?

Edward: An increase in velocity.

Researcher: What's the velocity right here (at the very beginning, it's zero).

Edward: Zero.

Researcher: So, if it does anything at all it's acceleration, right.

Edward: Right.

Researcher: So if I put more mass on here, what's that going to do to the acceleration.

Edward: Increase it.

Edward incorrectly stated that,

> *…if you have 500 grams on one end and 500 grams on the other, it [the two masses] should be level...If mass one and mass two were equal, then they should balance at whatever position they are at…If one's up here and the other one is down here, then they should stay there because they have the same mass.*

The researcher focused the discussion on the hockey puck and asked:

> *The hockey puck is moving along and this thing is going to get a kick. What happens to the force of that kick? If the puck is moving along and you take a stick and hit it, what happens to the force?*

Edward's response was:

> *It increases the acceleration…. It should stay on the puck because gravity is pulling down on it so that there's another force pulling on it. So, when it runs out of the hit, then it will stop.*

Edward realized that striking the hockey puck created an acceleration of the puck. However, he continued to believe that the force continued with the puck.

The discussion moved to the example of exerting a force on the back of a car:

Researcher: Let's look at this example. You stand behind your car and you go to push your car. Is the car going to accelerate?

Edward: Yes.

Researcher: Are you exerting a force on the car?

Edward: Yes.

Researcher: So what is the result of a force?

Edward: An acceleration.

Researcher: So if you're pushing the car is the car accelerating.

Edward: Yes.

Researcher: Once you take your hand off the car, what's the car going to do as far as acceleration is concerned?

Edward: It's going to start to slow down and the acceleration starts to decrease.

Researcher: Is that a positive or negative acceleration?

Edward: Negative acceleration.

Researcher: While your pushing the car is the acceleration positive or negative?

Edward: Positive.

Researcher: When you take your hand off of the car is the acceleration positive or negative.

Edward: Negative.

Researcher: Let's think back about the hockey puck. The puck is moving and when you hit it what's going to happen?

Edward: Increase the acceleration.

Researcher: And when you take the stick away what's going to happen to the acceleration?

Edward: start decreasing.

Researcher: Now, when there is an acceleration is there a force?

Edward: Yes.

Researcher: When there is no acceleration is there a force?

Edward: No.

Edward correctly understood that pushing a car created a positive acceleration and that removing the force from the car created a negative acceleration. Further, Edward understood that a force created an acceleration and that no force, there is no acceleration.

The final portion of this discussion involved returning to the original question related to the hockey puck:

Researcher: So, when that hockey puck begins to decelerate is there a force exerted by the stick still acting on the puck?

Edward: Yes.

Researcher: The hockey puck is slowing down. So is there a force still acting on the stick when the puck is slowing down?

Edward: Yes.

Researcher: Why do you say that?

Edward: Because the forces will probably continue until it stops…..

Researcher: Force causes what?

Edward: Acceleration.

Researcher: Is it acceleration or is it moving?

Edward: Acceleration.

Researcher: Acceleration, not movement. So when that hockey puck begins to slow down, is that force still acting on that hockey puck.

Edward: It's not.

Researcher: Correct.

At the conclusion of this discussion, Edward understood that the force of the hockey puck ceased after striking the puck.

Phase III - The New Knowledge Activity

Edward began the second phase with a discussion of his idea of force.

Researcher: Tell me about your idea of force.

Edward: Force is anything acting on an object that causes it to move. It's kind of hard, it causes motion in the x direction. Force is acting…..

Researcher: What's the result of a force?

Edward: Acceleration.

Researcher: Talk to me about mass.

Edward: It's the, um…..what an object is composed of?

Researcher: What about acceleration?

Edward: (thinking)… force divided by mass. As an object changes its speed.

Researcher: So, it's the change in velocity divided by what?

Edward: Divided by time.

Researcher: When we had our first interview we talked about a hockey puck. The concept was related to the forces acting on it in motion. Do you remember what we discussed?

Edward: The concept was the force acting on the puck in the air, the friction and the force of the stick on the puck.

He incorrectly stated that a force was anything acting on an object that causes it to move. He finally and correctly explained that force created acceleration. When asked about the meaning of mass, he stated that mass was, "what an object was composed of." The researcher asked Edward to describe acceleration; he responded with an algebraic manipulation of Newton's Second Law – acceleration is force divided by the mass. When pressed for the fundamental meaning of acceleration, he correctly stated that acceleration was the change in velocity divided by time.

The researcher administered the new knowledge activity:

Researcher: Let's talk about the exercise. There are four different scenarios. Identify the forces acting in each scenario.

Edward: In number one, the weight, the air friction, the normal force.

Researcher: What about number two?

Edward: The air friction, the weight and normal force.

Researcher: Tell me about the weight. Which way is it pointing.

Edward: Down.

Researcher: And the friction?

Edward: Friction is against the direction.

Researcher: And the normal. How did we define normal?

Edward: I'm having trouble with that one.

Researcher: How did we define normal? So, if something is on a surface which way is the normal.

Edward: Straight up.

Researcher: What about if something is on a slope

Edward: It's at an angle.

Researcher: Talk about a normal of ball number two.

Edward: Oh, I see, normal force is up and to the left.

Researcher: Why is that?

Edward: Because it's at a slope

Researcher: How did we define normal force?

Edward: From the perpendicular.

Researcher: From the surface on which the ball is resting?

Edward: But it's not resting.

Researcher: Right, so is there a normal force?

Edward: No, there's no surface and there's no surface.

Researcher: What about number three?

Edward: I said the weight and the normal force, but there's no normal force.

Researcher: What about number four, after the ball has landed?

Edward: I put the weight and the normal force.

Researcher: What force does the club exert on the ball, what happens to the force?

Edward: The force dissipates as it goes down.

Researcher: So, does that force still acting on the ball.

Edward: No.

Edward correctly answered most questions on the activity (see Appendix I); he correctly identified all forces on a golf ball, from its initial position on the ground, through its trajectory and finally, to its position on the ground. Edward missed the question related to the normal force. He stated that the normal force was present as the ball became airborne. The researcher asked Edward to define the normal force. He responded, “I’m having trouble with that one.” Finally, when prompted with part of the correct concept, he finally said that the normal force was the force perpendicular to the surface; thus, “…there’s no surface and there’s no normal force. Edward presumably understood that the force from the stick ended. However, during the second phase, Edward stated, “force is only being applied when there’s acceleration. But I don’t understand.” He was somewhat exasperated with the discussion, realizing that this concept was counterintuitive.

Edward’s initial understanding was that the “force” of momentum continued with the puck. After the discrepant event, the researcher asked Edward about the accelerating force. Edwards stated that, “…it should stay on the puck because gravity is pulling down on it so that there’s another force pulling on it.” Edward continued to believe that the force continued. He stated that, “…the force will probably continue until it stops.”

In summary, Edward began the investigation with three misconceptions. They were: (a) he believed that the force that acted on the hockey puck continued; (b) Edward mistakenly believed that equal masses suspended from the Atwood Pulley would self-level themselves; (c) Edward made no distinction between acceleration and speed, believing that they were synonymous (see Table 4).

At the start of the second phase, Edward stated that, “I used to think that force was still being applied even after the object is in motion. Force is only being applied when there’s acceleration.” Though his statement was correct, Edward continued, “…but I don’t understand.” Thus, he had not reached the point of intelligibility for this concept.

Phase IV - Conceptual Change Strategies

At the end of the second phase, Edward indicated that, “my initial understanding was I thought a force when it left the club was still acting on it. Now I know that no force is acting on it. Only when it’s applied initially.” Though Edward offered this statement, he did not understand the concept, nor did he believe it to be true, thus, the concept was neither plausible nor fruitful (see Table 3).

Edward was aware of his conceptual limitation when the researcher asked him to discuss his FCI response, “…the only thing that I can think is that I figure that momentum is affected by the friction although there is minimal friction on the ice….” (see Table 3). Edward utilized metacognitive evaluation when, at the end of the second phase, the researcher asked him to describe the cause of his misunderstanding. He responded that, “I think I’m having problems with the algebra. Math aside, I’m still having problems with the sum of the forces,” which was his assessment of his struggles with the concept. He further asserted that, “I have this book (Schaum’s Outline). I work the examples and sometimes my answers don’t correspond to the book’s answers,” which was his personal evaluation of his lack of success. Edward did not demonstrate the use of metacognitive regulation, nor reflection.

Edward did not undergo conceptual change and admitted his struggles with, physics and with basic algebra. He stated that, “I think I’m having problems with the algebra. Math aside, I’m still having problems with the sum of the forces.” Thus, Edward’s problems involved more than just understanding the concepts. He quantified his struggle with understanding the concept at 6 out of 10 (see Table 5).

When asked to complete the posttest, Edward selected the incorrect response to the question associated with the Hockey Puck misconception. Thus, Edward did not successfully undergo conceptual change.

Of the students assigned to study this misconception, Aaron, Benjamin and Caleb experienced conceptual change; Doug and Edward failed to undergo conceptual change.

The Elevator Misconception

Inventory item #18 posed the question regarding an elevator moving upward at constant velocity by a steel cable. The question asked students to select the response that described the forces acting on an elevator. The multiple-choice responses were as follows:

a. the upward force on the elevator by the cable is greater than the downward force of gravity

b. The amount of upward force on the elevator by the cables equals to that of the downward force of gravity.

c. The upward force on the elevator by the cable is less than the downward force of gravity.

d. It goes up because the cable is being shortened, not because of the force being exerted on the elevator by the cable

e. The upward force on the elevator by the cable is greater than the downward force due to the combined effects of air pressure and the force of gravity.

The correct answer was ‘b’, which described “equilibrium”, the absence of acceleration. During equilibrium in the vertical direction, all forces in that direction must cancel. Thus, the upward force generated by the cable’s tension must equal the force generated by gravity. Seventy-five students chose response ‘a’, four chose response ‘c’ and six chose response ‘e’, which suggested a misunderstanding of forces in the absence of acceleration.

The category of Superposition of Forces (adding of force vectors) set the focus of this research dissertation for the second of two misconceptions. The author of this investigation will refer to this misconception as “The Elevator Misconception.”

The researcher sought conceptual change by utilizing a four-phase approach. The intent of Phase I, Acknowledgment of Understanding, was to encourage the student to discuss and explain their FCI responses, to articulate and to provide support for personal ideas, and to articulate their understanding about the physical phenomenon as related to the Teaching for Conceptual Change Lesson Plan (see Appendix D).

The goal of Phase II, Collecting Evidence, was to confront the students’ understanding with reality by utilizing the discrepant event. With the Elevator Misconception, this was accomplished by, again, considering the acceleration of the Atwood Pulley (see Figure 2) under two conditions: (a) supporting equal masses which equated to zero net force, and (b) and supporting unequal masses, suggesting a non-zero net force. Finally, the researcher and the student performed the discrepant event and observed the outcome. This strategy focused on moving the student toward understanding that when the net force is zero Newtons (supporting equal masses), the resulting acceleration is zero m/s^2; when the net force is not zero (unequal masses) Newtons, the system accelerates.

Phase III, The New Knowledge Activity, occurred after a formal study of Newton's Laws and began with a discussion of the students' understanding of force, mass, acceleration, velocity, and the misunderstood concept. If, at this point, the student held to the prior conception, the researcher engaged the student into an additional discussion attempting to promote conceptual change. This discussion centered on the idea of pushing an automobile and the understanding that "pushing" suggested a positive net force and a positive acceleration and that "not pushing" suggested a net negative force and a negative acceleration; a car cannot positively accelerate without a net positive force. The new context activity for the elevator misconception involved a space vehicle in outer space equipped with four rockets: one on the front, rear, top and bottom (see Figure 4). The rocket contained two force meters, one capable of registering positive or negative forces in the x direction and the other capable of registering positive or negative forces in the y direction. This activity involved firing one or more of the rockets and asked the student to determine which of the scales registered the forces and whether the registered force was a positive or negative force.

Phase IV, Conceptual Change Strategies, focused on the strategies utilized by students who successfully underwent conceptual change. They were (a) dissatisfaction with the existing conception; (b) ability to comprehend the new conception (intelligibility); (c) believing the potential conception to be true (plausible); (d) finding the new conception usefulness (fruitful) proposed by Posner, Strike, Hewson and Gertzog (1982) in their Conceptual Change Model (CCM). Table 2 outlines the research findings relative to the hockey puck misconception and CCM. Awareness, evaluation, regulation and reflection are strategies required for undergoing conceptual change. Table 3 provides a summary of the conceptual change strategies (Wilson, 1999; Ertmer & Newby, 1996).

Table 6 summarizes the elevator misconceptions. This misconception was based on the relationship of the tension force and weight force of an object moving under constant velocity. According to Newton's First Law, the sum of vector forces acting on an object moving at constant velocity must be zero in that direction (correct conception). The majority of students did not understand that conception.

The researcher used this misconception to focus on the upward vector direction of the tension and the downward weight vector within the context of an elevator undergoing four types of kinematic motions. The four types of motion were (a) traveling upward with an acceleration of zero m/s^2; (b) traveling upward with non-zero acceleration; (c) traveling downward with an acceleration of zero m/s^2; (d) traveling downward with non-zero acceleration. The goal was to examine a students' initial conception of the relationship between the tension vector and the weight vector under those four conditions and to attempt to convert any non-scientific concepts into those accepted by the scientific community.

Table 2 provides a summary of the conceptual change strategies as associated with the CCM. Recall that the CCM proposed by Posner, Strike, Hewson and Gertzog (1982) suggested that students must adopt four prerequisites that will pave the way for conceptual change. They were (a) dissatisfaction with the existing conception; (b) ability to comprehend the new conception (intelligibility); (c) believing the potential conception to be true (plausible); (d) finding the new conception usefulness (fruitful) (Posner, Strike, Hewson & Gertzog, 1982). Wilson (1999) and Ertby and Newby (1996) listed awareness, evaluation, regulation and reflection as conceptual change strategies required for undergoing conceptual change. Table 3 provides a summary of the conceptual change strategies.

The researcher assigned Fred, Gary, Harold, Isaac and Jack to study the elevator misconception. All five students began the investigation with the same misconception about the relationship between the tension force and the weight force under positive or negative accelerations. Of the five students assigned to study this misconception, only Gary underwent conceptual change.

Phase I - Acknowledgment of Understanding – Fred

Fred was a 36-year-old African male studying textile engineering technology. Fred did not list a high school GPA but indicated that his college GPA was 2.17/4.0. He indicated that all pre-college course were taken at the regular level. His academic standing in Physics I at the time of this writing was 90%. His answer for question #18 on the FCI was "c," the upward force on an elevator by the cable is less than the downward force of gravity for constant upward velocity.

The researcher asked Fred to elaborate on his FCI response:

Researcher: What we're going to look at here, I'm going to read it to you. It says an elevator is being lifted up an elevator shaft using a steel cable. When the elevator is moving up the shaft at constant velocity you were supplied with five questions. Your answer was that the "upward force on an elevator by the cable is less than the downward force of the gravity.

(Repeat)…….Now this thing is moving upward at constant speed. Remember that????? Tell me how you came up with that answer.

Fred: The upper force was less than the downward force. (Thinking)……I don't know if I answered the question right. From my own thought, I would think that the upper force would be greater than the downward force in order for it to go up.

Researcher: So you think that the …So if you had an elevator (drawing a diagram)…..so here is the cable and here is the force due to the gravity. So, tell me which one….if this thing is moving upward at constant velocity and the velocity is not changing and we'll call that a tension (pointing to the upward arrow), which one of those would be greater.

Fred: The velocity if constant and the weight ……..(thinking)……ok from my own understanding force is mass times the acceleration. So, um, the force on this weight which the acceleration, we're talking about acceleration due to gravity acting on the downward force is 9.8 m/s2, so the greater force would be on the cable that's holding the elevator up.

Researcher: So, tell me how you came up with that answer. Tell me why you think that that would be the right answer.

Fred: Well, the elevator at rest has a downward force of the mass and the acceleration due to gravity. Now, in order to get the elevator off the ground, it would have to need a greater force to overcome the force which is holding the elevator at rest. One of the Newton's laws is a body at rest continues to be at rest until another force changes that. That's my understanding of that.

He stated that:

> *From my own thought, I would think that the upper force would be greater than the downward force in order for it to go up. Well, the elevator at rest has a downward force of the mass and acceleration due to gravity. Now, in order to get the elevator off the ground, it would have to need a greater force to overcome the force, which is holding the elevator at rest.*

Though he recognized Newton's Second Law, Fred was under the impression that constant velocity needed a marginal amount of force to continue moving at constant speed.

Phase II - Collecting Evidence

To confront the first misconception, which was related to the tension/weight vectors, the researcher initiated the discrepant event. The researcher introduced the Atwood Pulley to Fred by asking him to record the reading on the spring gage for one of the suspended weights (see Figure 3); Fred did that.

Researcher: When you look at this sitting still, what is the relationship between the force up here (pointing to the string) and the force here (pointing to the weight)?

Fred: The relationship?

Researcher: Is the force here (pointing to the string) greater than or less than the force here (pointing to the weight).

Fred: As it is hanging right now. It is greater than the force on the.

Researcher: Which one is greater, the tension or the weight?

Fred: The…...tension is the same as the force….the tension is greater.

Researcher: Now what I'm going to do is I'm going to raise it all the way to the top and I want you to kind of tug on it to get it to move at constant speed and I want you to watch the needle as it's coming down. And watch the needle and see what the needle does. (demonstrating as the system moving at constant speed) What do you see the needle doing.

Fred: The needle is not changing. It's not changing

Researcher: It's not changing. Ok. See what's required to get that needle to change. What would you have to do in order to get the needle to change?

Fred: I don't know, maybe decrease the speed…And, the needle is recording the weight of the……….it's going to remain the same……cause …..and the only time that I think that the needle would change is at high elevations or so, where the pull of gravity is not the same as ….closer to the earth.

Researcher Now, one other thing I want you to consider. What's going to happen when this thing hits the ground…….what is the needle going to do when it suddenly hits the ground……what do you think that the needle will do.

Fred: (writing)………ok, I know the…if it hits the ground……….alright, I think it's going to be the same…..because the tension will be a hold that's holding the cylinder, so the force will be the same.

After observing the discrepant event, Fred responded:

Researcher: Ok, so let's see what's going to happen. I'm going to start this thing to moving at constant speed and I want you to look at the needle and tell me what's it's doing. (demonstrating the system moving at constant speed)……

Fred: It's not changing.

Researcher: Is that consistent with what you thought?

Fred: Yes.

Researcher: Ok, so that's the same. It's moving the same speed and the needle is not changing. So, right now, I'm going to let it hit the ground and let's see what happens (demonstrating).

Fred: I think I understand what happened. I was thinking in terms of this other cylinder, but I think it's only going to show the mass of this cylinder which is going to be less than the actual cylinder.

Researcher: Explain to me cause I'm not understanding.

Fred: There's the difference between mass and weight, right. Um……..the……because what I saw the needle doing is getting less and less so, ok, so I understand this……as it is it's showing the tension force…is it the tension or the tension force …….or the force acting on the………

Researcher: You tell me…what's it reading…

Fred: I would say that it's reading the tension force…

Researcher: Why?

Fred: Because that the force that is holding the cylinder up….so now when it hits the ground there's not force holding the cylinder up so the force is going to go to zero.

Researcher: So, you're saying that when this thing hits the ground, what's it going to do?

Fred: I think the needle is going to go to zero cause there's no force holding it up.

Researcher: I see…..ok, you're right, it did just what you said it was going to do, (crash with the apparatus falling apart). Ok now you have your prediction down. So, the question is not is your prediction the same? Is your prediction the same as what actually happened.

Fred: No, it's not.

Researcher: Ok, why not?

Fred: Because there is no force acting on the cylinder once it hits the ground in the upward direction.

Researcher: And so, it's not the same and in that case, in that case you would put no….Now let's talk about your understanding that you had before because when you first came in I told you that…what you told me what that the forces were not the same…..when the elevator was moving at constant speed, the force generated by the tension and the force generated by the weight were different. What do you believe now…..if something is moving at constant speed…….

Fred: At constant speed…um….I say that the force generated by the tension is greater than he force generated by the weight.

Researcher: When this thing is moving at constant speed and this not changing in velocity, you still believe that the force generated by the tension and the force generated by the weight are not the same.

Fred: They're not the same.

Researcher: Ok, that's where we're going to end………

Upon providing a positive acceleration by quickly pulling upward on the string with the discrepant event, Fred still did not accept that the increased tension was attributable to the acceleration:

> *I think I understand what happened. I was thinking in terms of this other cylinder, but I think it's only going to show the mass of this cylinder which is going to be less than the actual cylinder.*

What Fred observed was the mass decelerating while hitting the ground. Fred interpreted this "moving" needle as a changing tension, which it was. However, he did not make the connection between the reduced tensions while hitting the ground to the tension/weight relationship. Fred noticed that the spring scale did not change while the system moved in either direction. The researcher asked Fred for his conclusion. His response was:

> *What I saw the needle doing is getting less and less so, I understand this…it's showing the tension force…the force is holding up the tension so when it hits the ground there's not force holding the cylinder up so it goes to zero.*

Fred maintained the misconception to the end of the first phase that “at constant speed, the force generated by the tension is greater than the force generated by the weight.”

In summary, Fred entered beginning physics, with three misconceptions: (a) Fred believed that the weight force of an elevator exceeded that of the upward tension force during constant motion, thus he was unclear about the effect of opposing forces acceleration; (b) he believed that force created motion rather than acceleration as Newton’s Second Law suggests; (c) he believed that mass and weight were equivalent (see Table 6).

Phase III - The New Knowledge Activity

By the time of the second phase, Fred had completed studying the course section on Newton’s Laws. The researcher asked Fred to review his idea of force, mass and acceleration:

Researcher: Let’s review. What is force?

Fred: Ok, force has magnitude and direction.

Researcher: What makes up force?

Fred: Force has to do with the weight of an object.

Researcher: What two things do you need to calculate force?

Fred: Mass and acceleration.

Researcher: Do you remember what mass is?

Fred: Mass is just the magnitude of the object that is the way that the gravitational pulls.

Researcher: And what about acceleration.

Fred: Acceleration is…change of velocity over time

Fred was still unsure of the composition of force because his follow-up comment was that force had to do with the weight of an object and that mass and acceleration comprised force. Fred indicated that, "Mass is just the magnitude of the object that is the way that the gravitational force pulls." Though true, it was an incomplete definition of force. However, Fred did correctly define acceleration as the change in velocity divided by time.

The researcher asked Fred to discuss his understanding of the concept under review – the relationship between the tension under positive, negative and zero acceleration:

Researcher: We talked about the elevator. Describe what we talked about. We dealt with how the tension varied with the weight. Tell me what you believed about that and about the relation between the tension and the weight under acceleration as opposed to constant speed. What was your initial impression.

Fred: I don't remember my initial impression.

Researcher: The first thing that we talked about initially was that if we have an elevator accelerating upward … how the tension compared to the weight.

Fred: Um, if the elevator is accelerating upwards the tension has to be greater than the weight for there to be an acceleration.

Researcher: That wasn't your first impression. Do you remember what your first impression was?

Fred: I think that it was the same.

Researcher: What was your impression at constant speed?

Fred: At constant speed……I don't remember.

Researcher: So, right now at constant speed it's what?

Fred: At constant speed, there's no acceleration so the tension is equal to the weight.

Researcher: How is it that you got to the point that when you're at constant speed up the tension is the same as the weigh versus how did you get to that point, cause that's what you say is correct.

Fred: I'd taken into consideration that acceleration…..and um….and I know now that at constant speed there's no acceleration.

The researcher again asked Fred about the relationship between tension and weight under constant speed. Fred stated that, "At constant speed, there's no acceleration so the tension is equal to the weight." This response was correct. The researcher then asked Fred to explain how he arrived at this point of understanding. He indicated that he had not realized that acceleration affected the tension as it did. Therefore, understanding the contribution of acceleration made the difference in understanding the concept. A second similar question regarding Fred's understanding confirmed this suspicion:

> *I had a hard time because I never understood the effect of acceleration. Once I got to understand the effect of acceleration and the direction it kind of made it easy to comprehend.*

The next conversation centered on Fred's understanding of the relationship between the tension force and the weight force of an elevator. Fred did not recall his earlier conceptions; however, he indicated that an elevator accelerating upward needed a tension that was greater than the weight of the object. This was surprisingly correct. Fred also stated that at constant speed, there is no acceleration and the tension was equal to the weight. When asked how he arrived at the correct conception he stated that:

> *I'd not taken into consideration that acceleration...I know now that at constant speed there's no acceleration.*

The researcher provided Fred with the exercise that would strengthen the understanding of the new conception (see Figure 4). Fred correctly responded to the first question. However, he incorrectly responded to question #2: he stated that the y-force would be equal to 100 Newtons when it actually would have been greater than 100 Newtons. Fred changed his answer when he verbalized the incorrect answer:

> *…it would probably be greater because for there to be an acceleration, it has to be greater than the weight.*

The remainder of Fred's responses were correct. His final summary of the discussion was:

> *I know if you have an acceleration in the x direction and there's no y component to the acceleration there's going to equal out and come to zero, so that, like for example the tension and the weight is equal so there's no acceleration like that. Likewise, if it's moving in the y direction positive or negative I know there's no acceleration in the x direction.*

Once Fred comprehended the concept, the misconception did not surface again in the second phase. However, Fred still chose the incorrect response of the posttest.

Fred appeared to understand the concept at times, and during others, he did not. One of his affirmative statements was that:

> *I think I understand what happened. I was thinking in terms of this other cylinder, but I think it's only going to show the mass of this cylinder which is going to be less than the actual cylinder…if the elevator is accelerating upwards the tension has to be greater than the weight for there to be an acceleration.*

Fred also demonstrated his understanding when asked to provide an example using this concept. His response was:

> *We're talking about the firing a rocket or an aircraft or maybe…maybe I can say the best example the elevator and a car traveling on a flat road…there's no acceleration in the y direction. I know that for cars to go forward or backwards the force has to be greater in one direction and whereas for an elevator accelerating up, the tension has to be greater than the weight.*

Phase IV - Conceptual Change Strategies

Fred's conceptual structuring resembled that of "weak" restructuring rather than that of "strong" restructuring (Carey, 1985). He appeared to have rearranged the relationships between existing concepts undergoing conceptual assimilation rather replacing them as would have been done with strong restructuring and conceptual accommodation. For example, Fred temporarily "located" and utilized the correct concept but returned to former conceptions soon thereafter, thus rearranging the concepts for the benefit of the moment. He did not accept the new conception as intelligible, plausible or fruitful.

Fred revealed his awareness of a learning limitation when, at the end of the second phase, he indicated that did not consider the acceleration in the scenario of the tension, "…before I wouldn't have considered just the magnitude of the force or even the direction, but I never considered the effect of acceleration on the magnitude of the force" (see Table 3). Fred utilized the evaluation metacognition strategy to promote conceptual change when he discussed his observations of the discrepant event. He stated that:

> *I think I understand what happened. I was thinking in terms this other cylinder, but I think it's only going to show the mass of this cylinder which is going to be less than the actual cylinder.*

Fred demonstrated no use of the regulation strategy, but did utilize reflection. The first instance of the use of reflection occurred when the researcher asked Fred to explain his answer on the new-knowledge activity. After initially providing the incorrect answer, he paused, and reflected on the previous discrepant event. His statement was, "…..well I don't know, it would probably be greater because for there to be acceleration it has to be greater than the weight."

Fred quantified his struggle with understanding the concept at 7 out of 10. He attributed his lack of understanding to not considering acceleration as part of the concept. He stated that, "I had a hard time because like I say, I never understood the effect of acceleration. Once I got to understand the effect of acceleration and the direction it kind of made it easy to comprehend…."

When asked to complete the posttest, Fred selected the incorrect response to the question associated with the Elevator misconception. Thus, Fred did not successfully undergo conceptual change.

Phase I - Acknowledgment of Understanding – Gary

Gary was a 19-year-old African-American male studying software engineering. His high school GPA was 3.3/4.0 and his college GPA was 3.17/4.0. In high school, Gary enrolled in regular level physics, Algebra I and II, geometry and trigonometry. He enrolled in AP Physics and Honors Algebra I. His academic standing in Physics I at the time of this writing was 80%. Gary's FCI response to question #18 was "a." He believed that the upward tension and downward weight vector during constant speed was that the upward force of the elevator is greater than the downward force due to gravity.

The first phase with Gary began with a discussion of understanding of the effect of opposing forces on acceleration.

Researcher: Ok, Charles and we're going to talk about the pre-test that you took. When I gave you the pre-test here's one of the questions that you answered. I'm going to read the question and identify the answer that you provided. I want you to tell me how you came up with that answer. The one that I have is that and "elevator is being lifted up an elevator shaft on a steel cable. When the elevator is moving up at constant velocity" the answer that you gave me was that the upward force of the elevator by the cable is greater than the downward force of gravity. So, if I have this diagram like this (pointing to the diagram) and this is the tension in the cable and this is the weight and this thing is moving up at constant speed that is the change in velocity is zero, you told me that this upward force is greater than this one here (pointing at the upward and downward arrows). Tell me how that you got that.

Gary: I actually figured that if the tension is greater and the force is able to pull the car up it has to overcome the gravity that is forcing it down because the force of gravity is the mass times the acceleration which is gravity and that's if it's in equilibrium because it's at rest. And to overcome rest, a force must be greater and since it's moving upward that means that the force greater than the force pulling it down.

Researcher: Ok, so what you still believe here is that this force (the tension force) is greater than this (pointing to the downward force) if this is to be moving upward? Um….tell me what you understand about tension and force. Just talk to me about tension and force.

Gary: Tension and force of gravity would be equal if an object is at rest and tension is basically the mass times the gravity in the cable and as far as the force of gravity always mass times acceleration and acceleration will always be 9.8 or constant for gravity and mass is always a variable.

Specifically, the researcher asked Gary if the upward tension during constant speed was greater, less than or equal to the downward force due to gravity.

Gary explained his answer as follows:

> *I actually figured that the tension is greater and the force is able to pull the car up; it has to overcome the gravity that is forcing it down because the force of gravity is the mass times the acceleration which is gravity and that's if it's in equilibrium because it's at rest. And to overcome rest, a force must be greater*

and since it's moving upward that means that the force greater than the force pulling it down.

Gary was partially correct in that the force of the tension should have been greater to results in an upward acceleration. However, his conception was still cloudy regarding the movement of the mass at constant speed. His follow-up comment was:

Tension and force of gravity would be equal if an object is at rest and tension is basically the mass times the gravity in the cable; and the force of gravity is always mass times acceleration and acceleration will always be 9.8 and mass is always a variable.

Phase II - Collecting Evidence

The researcher asked Gary to predict the behavior of the Atwood Pulley under positive, negative and zero acceleration:

Researcher: Ok, now what I'm going to do….you've got this sheet that I'm giving you…..right here….and I've got a setup and what we're going to do is to pretend that this is an elevator. And that this is the tension (pointing to the string) and that this scale is going to reflect the weight here (pointing to the mass). So basically this is the elevator, this whole assemble. The question that I have for you is that if this is the tension going up and we have an mg going down and the this moves up at constant speed the question is what do you think what this would read here.

Gary: This spring gauge.

Researcher: Yes, this spring gauge. This gauge right now is reflecting the weight that is being hung here which is the elevator, essentially. So, if you have a 500 gram elevator, this is going to reflect 500 grams…..if you….if this thing moves upward at constant speed, how is this going to change is the question.

Gary: I believe that the needle has a slight increase (writing).

Researcher: Ok, that's the prediction that I want you to write down, and that's at constant velocity. What do you think would happen if the velocity is not changing. What do you think would happen…..would the needle change or not…..stay the same or not change.

Gary: Increase…..steady increase

Researcher: We're talking about steady increase now….a steady increase as it picks up speed as it's going up. Do you think that as it's picking up speed this needle is going to increase, decrease or remain the same.

Gary: Increase….

Researcher: You think it's going to increase. Write that down…….What about for a downward acceleration.

Gary: Decrease….

Gary incorrectly predicted that the tension would slightly increase at constant velocity and incorrectly predicted that the tension would remain the same during positive acceleration. After observing the demonstration, Gary realized that his predictions were incorrect.

The researcher and Gary observed the discrepant event in which the researcher asked the student to consider the Atwood Pulley (see Figure 3) and to discuss the tension of a mass under positive, negative and zero acceleration:

Researcher: Now, I'm going to start this thing to moving at constant speed and I want you to focus on this needle here. Tell me what you see…(demonstrating)…..focus on what it's doing.

Gary: slight increase.

Researcher: What's it reading now.

Gary: five….more that five….560 grams……

Researcher: Ok, let's see what it's going to read as it's going down (demonstrating)

Gary: It doesn't really look like its changing.

Researcher: So, then is your idea that it's changing or staying the same as it's going at constant velocity.

Gary: Staying the same.

Researcher: Now, under…..the tension is going to increase as it's accelerating up. Now I'm going to yank this up which is going to cause this to accelerate down and see what happens (demonstrating). Did it increase or decrease.

Gary: Decrease.

Researcher: And that's just what you said it was going to do. Please write that down. The stuff that you predicted, is it all the same.

Gary: All except the constant acceleration.

Researcher: So, what you said is that with constant velocity upward it was going to do what

Gary: Increase.

Researcher: So, what actually did happen?

Gary: It had a constant tension.

Researcher: And what accounted for that difference. Because, you said one thing and another thing happened, so what do you think about that.

Gary: I think that if I do different, I should have thought more about the scenario and actually thought more about what would have happened ….it seems with an impulse in either direction it would show a big change…..but with something that is constant there would be no physical change.

Gary seemed to have undergone conceptual change during the first phase. However, the actual change may have been a "shallow" conceptual change rather than that of "deep" conceptual change.

In summary, Gary began the research investigation with three misconceptions: (a) he maintained weak understanding of the relationship between the upward tension and downward weight force thus not understanding the relationship of opposing forces and the resulting acceleration; (b) Gary believed that force created motion; and (c) his understanding of acceleration was incorrect (see Table 6).

Phase III - The New Knowledge Activity

The second phase commenced with the completion of the new-context exercise.

Researcher: Let's talk about the exercise that I gave you. I gave you a rocket and the rocket has four booster rockets. If you ignite the first nozzle, it will accelerate in the positive x direction. If you ignite Nozzle 3 it will accelerate in the negative x direction and so forth. Let's look at the first one…..you fire rocket one what happens?

Gary: In the x direction, the weight will be greater than zero Newtons and equal to 100 Newtons in the y direction because there's to displacement in the y and since it's increasing in the x direction it increases the acceleration and the force is greater.

Researcher: Let's say that this is not accelerating at all, it's just hovering in space. Let's say that it's not accelerating. What's the y value going to read if the weight given for a person sitting on it is 100 Newtons.

Gary: It's going to read 100 Newtons.

Researcher: So if you fire Rocket #1, your idea is going to get greater than zero Newtons on the x.

Gary: Right.

Researcher: Talk to me about firing #2.

Gary: 2, I believe it will be equal to zero Newtons in the x direction and greater than 100 Newtons in y direction

Researcher: And what about #3?

Gary: 3, I said that will be less than zero Newtons in the x direction and equal to 100 Newtons in the y direction

Researcher: And #4…..

Gary: Four, in the x direction, equal to zero Newtons and less than 100 Newtons in the y direction.

Researcher: Tell me why you came up with those, in a general sense.

Gary: For rocket #2 is pushing on the bottom, as you say it's pushing in the positive y direction, so it's no displacement in the x direction so x is going to remain zero. And since it's increasing in the y direction it's going to be a positive acceleration there fore the force will be a positive number. For #3 it's pushing in the negative x direction so the acceleration would be negative making it less than zero Newtons and the same thing for the fourth rocket with it pushing down in the negative y direction it's going to be less than the 100 Newtons and no displacement on the x direction so it remains at zero Newtons.

Gary answered all questions correctly. However, when asked to explain his answer to the first question, Gary said:

> *In the x direction the weight will be greater than zero Newtons and equal to 100 Newtons in the y direction because there's no displacement in the y and since it's increasing in the x direction it increases the acceleration and the for is greater.*

Though Gary appeared to have undergone conceptual change, he still conceptualized "displacement" rather than acceleration.

Gary's conception of the relationship between the upward tension and the downward weight forces were partially incorrect. Additionally, he believed that force created motion, and his definition of acceleration was incorrect. When explaining his position on the tension and weight forces, Gary stated that:

> *I actually figured that if the tension is greater and the force is able to pull the car up it has to overcome the gravity that is forcing it down because the force of*

gravity is the mass times the acceleration which is gravity and that's if it's in equilibrium because it's at rest. And to overcome rest, a force must be greater and since it's moving upward that means that the force greater than the force pulling it down.

Gary's account of "pulling" a car up is correct. However, the correct terminology would be "acceleration" rather than "pulling." The discrepant event provided the context for Gary to confront his slight misunderstandings of the elevator misconceptions. After observing the discrepant event, he stated that:

When it pulls up, it was an increase because there was more pressure and it felt like there was more mass and tension...the tension decreases going down.

Though his ideas were correct, he again equated "pulling" with acceleration. This notion surfaced at the second phase in which the researcher asked Gary to define force, mass and acceleration. He did fine with force and mass, however, Gary described acceleration as displacement divided by time, which was incorrect. Again, the researcher confronted this definition with the correct one, which pointed out the error to Gary.

Gary reviewed his conceptions of the relationship between the tension and weight during this phase:

Researcher: What is the concept here that you think that we have?

Gary: Um…the concept I believe, if it's a negative direction then the acceleration is going to be negative therefore the force will be negative.

Researcher: What about the relationship about force. What makes force?

Gary: The mass times the acceleration for the x or the mass times the gravity for the y.

Researcher: And what's mass?

Gary: Mass is not weight, but basically what an object is made up of. It's composite.

Researcher: What about acceleration?

Gary: Acceleration would be its displacement over, speed over a given time.

Researcher: What are your ideas now about the relationship between force and mass and the direction? Let's say that you have an acceleration that is positive. How is that going to effect the force? If you have a positive acceleration in the y direction what is that going to do to the force?

Gary: The force would be greater in a positive aspect.

Researcher: What if you have an elevator accelerating up. How's that going to effect the tension?

Gary: Tension going up would be actually, increasing also.

Researcher: Do you know why?

Gary: Because the acceleration is increasing.

Gary said that:

> *Tension going up would be actually, increasing...because the acceleration is increasing.*

Gary demonstrated his understanding of the concepts when asked to complete the new knowledge activity (see Figure 4). Additionally, the researcher asked Gary how to solve the for the acceleration with more than one rocket firing. Gary responded that:

You'd get the magnitude in the x direction then find the magnitude in the y direction and find the, I guess it would be a perfect triangle and use the Pythagorean theorem to find the hypotenuse for the resultant vector.

The answer is somewhat correct in that using the Pythagorean theorem would correctly solve the problem.

Gary seemed to have successfully dealt with the misconception. The conversation then moved toward the meaning of force. He responded that, "Force creates movement," which is incorrect. The researcher asked Gary to consider Newton's Second Law and to describe force. Gary correctly indicated that force was the product of mass and acceleration. So, the researcher asked him to compare motion and acceleration. He realized that his earlier response was incorrect and that force created acceleration, not motion. These interviews suggest that Gary underwent conceptual change. However, Gary did not choose the correct responses on the posttest.

Gary initially believed the following, which was correct:

I actually figured that if the tension is greater and the force is able to pull the car up it has to overcome the gravity that is forcing it down because the force of gravity is the mass times the acceleration which is gravity and that's if it's in equilibrium because it's at rest.

However, it did not take much for him to "clean up" his other misconceptions. Gary benefited from the discrepant event in that he observed the outcome, which ultimately changed his understanding to the scientifically accurate conception. The researcher asked Gary to articulate this thinking on the topic. Gary said that:

> *I think that anything in constant tension will stay the same cause only on sudden burst or sudden jerks for the impulse will it change.*

To ensure that Gary correctly comprehended the meanings of "sudden bursts" or "sudden jerks" the researcher asked for an explanation. Gary correctly inserted "acceleration" and correctly understood that, "acceleration is change in velocity displacement divided by time." Therefore, Gary successfully underwent conceptual change.

Phase IV - Conceptual Change Strategies

Though Gary successfully underwent conceptual change, one might attribute his failure to demonstrate any dissatisfaction with his existing conception to his quiet nature (see Table 2). He, however, did demonstrate an awareness of the deficiency in his understanding. The researcher asked him to account for the difference in his prediction of the discrepant event and the actual outcome. His response was:

> *I think that if I do different, I should have thought more about the scenario and actually thought more about what would have happened...it seems with an impulse in either direction it would show a big change...but with something that is constant there would be no physical change*.

The impulse to which he referred, is the sudden "jerk" that caused the system to accelerate that would have resulted in an increased or decreased tension. Gary also referred to a "constant" that resulted in "no physical change." Again, Gary correctly suggested that constant velocity would result in no change in the tension. Thus, he was aware of the distinction, revealing wholesale conceptual change (Demastes, Good & Peebles, 1996). Gary's comment suggested that this conception was intelligible and plausible. Gary did not directly state that it was fruitful, but he certainly did benefit from understanding the new conception by utilizing it to answer all questions correctly on the new-knowledge activity. Thus, he indirectly demonstrated fruitfulness in that he replaced the prior conception with a scientifically appropriate one.

Gary entered college with a substantial foundation of science courses. He had enrolled in Advanced Placement (AP) Physics as well as in Honors Physics in high school. Thus, his skill development and expertise were directly related to prior use of deliberate practice (Ericcson, 1996). The suggestion is that the more one practices, the better one gets without regard to initial talent and ability. This deliberate practice seemed to promote conceptual change for Gary (see Table 3). Though he demonstrated ability and skill level, Gary did demonstrate awareness during the investigation in which he metacognitively stated that:

> *I think that I would have done differently…I should have thought more about the scenario and actually thought more about what would have happened…it seems with an impulse in either direction it would show a big change…but with something that is constant there would be no physical change*

Evaluation is the judgment made regarding one's thinking capacities and limitations as these are employed in a particular situation.   Further, it is the assessment of the effectiveness of their thinking or strategy of choice. Gary exhibited evaluation within the same previous quote. He indicated that, “I should have thought more about the scenario and actually thought more about what would have happened.” He assessed the effectiveness of his thinking, realizing that an alternative strategy may have been more beneficial.

Regulation draws upon knowledge and makes effective use of available cognitive resources. The quality of regulation refers to how effectively one engages in intentional conceptual change. Low quality regulation refers to poor planning, little monitoring; high quality regulation refers to careful planning and monitoring (Ferrari & Elik, 2003). According to Zimmerman (2001), one's self-efficacy relative to intentional conceptual change influences the degree to which one is able to make the required conceptual change. Through the talk-aloud sessions, Gary did not demonstrate any instances of metcognitive regulation. His college preparation obviously allowed him to develop a healthy sense of self-efficacy, which is likely attributable to his conceptual change.

Reflection refers to the action undertaken by the student when considering the choices, actions and results have resulted from awareness, evaluation and regulation. During reflection, the learner decides on whether or not to continue or to make changes in the strategy (Schunk, 2000). Gary certainly demonstrated reflection in that he realized that more than one way existed to solve a problem. The researcher asked Gary to hypothetically determine how to determine the magnitude of the acceleration given the magnitude of the firing force of two rockets. Gary’s response was:

> *You’d get the magnitude in the x direction then find the magnitude in the y direction and find the perfect triangle and use the Pythagorean theorem to fine the hypotenuse for the resultant vector.*

Had Gary been asked to solve the problem, he would have been able to exercise choices in the method chosen. At the end of this conversation regarding the hypothetical problem, Gary offered yet another way to solve the problem. He indicated that:

Um…you could assume that would be a 45degree angle so you would take the cosine of the magnitude from rocket one or the sine from rocket two.

Again, Gary utilized his depth of knowledge to reflect on distinct strategies to satisfy the problem.

Gary experienced conceptual change. He completed regular and Advanced Placement (AP) physics in high school as well as regular and honors algebra in high school. At the start of the investigation, Gary's conceptions were partially correct. Though he chose the incorrect response on the pretest, he demonstrated a slight understanding of the concept during the phase. Thus, his quantification of the level of difficulty for understanding the concept was 3 out of 10 (see Table 5). When asked about the struggle to understand the concept, he responded that, "…it really was not hard for me to understand the concept. I just had to get the directions right and understand that acceleration contributed."

When asked to complete the posttest, Gary selected the correct response to the question associated with the Elevator misconception. Thus, Fred successfully underwent conceptual change.

Phase I - Acknowledgment of Understanding – Harold

Harold was a 23-year-old European-American male studying information technology (IT). He did not list a high school GPA but indicated that his college GPA was 3.05/4.0. Harold completed regular level physical science, physics, Algebra I and II, geometry and trigonometry. He completed AP Calculus in high school. Harold's academic standing in Physics I as of this writing was 61%. Harold chose "a" for question

#18 -- the upward force on the elevator by the cable is greater than the downward force of gravity.

When the researcher asked Harold to elaborate on his FCI answer, he explained his answer as follows:

Researcher: The elevator is being supported by a couple steel cables. It's moving upward at constant velocity…and the question asked is if the elevator is moving up the elevator shaft at constant velocity it gives you five choices. One of the questions is the upward force of the elevator by the cable is greater than the downward force. I think that's the answer that you gave. (Repeat the choice). What do you think about that…?

Harold: The upward force……..thinking…….I don't know….obviously the cable pulling up is overcoming the pull of gravity, so then if it's overcoming the pull of gravity, assuming if I said that gravity and the cable is the only two things that can act on the elevator's movement then I would say that the cable would have to overcome it, so I would say that it has more…..

Researcher: You're saying that the upward force is greater than the downward force of gravity.

Harold: Right, otherwise it would be going down instead of up.

Harold believed that the upward tension must be greater than the weight force under constant speed, which is incorrect.

Phase II - Collecting Evidence

The discrepant event discussion, which focused on the Atwood Pulley and the relationship of the tension of each cable to the weight under varying accelerations (see Figure 3), began with a long excerpt with the researcher coaxing a prediction from Harold:

Researcher: So my question again to you while this thing is moving at constant speed, what is the relationship between these two things (pointing to the upward tension and the supported weight). Is one larger than the other, or is the other larger than the one, are they equal.

Harold: They're equal to a point….until momentum plays out.

Researcher: Until momentum plays out, ok…

Harold: If they're both at different levels and they're still, then they're not going to move but once you give it a direction as velocity in either the positive or negative direction, no that's not velocity, anyway once it has momentum in a 3d space in any direction, then the gravity, the force that the string produces is the same but its effect is multiplied.

Researcher: Let me, um, what I want you to predict is that I'm going to pull this down to get this thing moving at constant speed and I want you to predict what will you think will happen as far as the velocity is concerned as this thing is moving.

Harold: As far as the elevator or just like the value of the velocity whether it's increasing or decreasing.

Researcher: The value of the velocity.

Harold: Thinking……..(mumbling…..the velocity, well)…….I think it's lower initially, it will be halted by the limitations of the pulley.

Researcher: Now, I also want you to focus on, we're talking about the force on this problem I want you to write down, when this thing is moving at constant speed, I want you to decide what you think the relationship is between the forces up and the forces down. We're talking about the forces here (pointing to the set up of the string) generated by the force up and the force generated by the force due to gravity. When this thing is moving at constant speed, what do you think the relationship is between the force in the string and the force due to gravity at constant speed?

Harold: I would say that the force doesn't change. Momentum does change, does change, and the effect of constant force and other forces.

When asked to predict the events associated with the discrepant event, Harold predicted that the tension would be greater than the weight in all cases –under both positive and negative acceleration and under zero acceleration:

Though he initially stated that momentum is not a force, his latter statement suggested his conceptual understanding that momentum was a force.

The researcher moved on to perform the discrepant event. Harold observed as follows:

Researcher: Ok, so what I'm going to do is that I'm going to cause this thing to move at constant speed upward, and I want you to focus on the needle. Demonstrating the set up…

Harold: (He's looking as the mass moves upward, then downward.)

Researcher: Ok, let's try it again… (demonstrating). Is that, it's different than from what you thought.

Harold: It's not a relationship between…

Researcher: When does it move?

Harold: It moves when it's opposite, I mean more or less, when it changes direction. Wait a minute (observing the demonstrating). It's greater than two.

Researcher: It is…? Ok, lets look at this one.

Harold: It's about staying the same…….It look like it might be trying to increase……think……….

Researcher; So it looks like it's staying the same…….

Harold: Yeah……

Researcher: Now, what I want you to do is to write your observations down…….

Harold: (writing and mumbling). The measurement stayed the same, the same amount of Newtons, the force being exerted on both sides….

Researcher: Ok, go ahead and write that down………

Harold: (mumbling) the weight was moving……..

Researcher: Ok, if that is the case now, keep in mind that these masses here (pointing at the masses) are generating the downward weights on the spring here. This string here is creating an upward force.

Harold: Right now, they're equal (moving the weights so that they are side by side)….

Researcher: Yeah, are they equal down here (moving the weights so that one is on the floor and the other is above). Does the height relative to where they are, have does that have anything to do with whether they are equal or not.

Harold: Well, it, I would think that the answer would be no, kind of, you think of air pressure or a magnetic core, the closer you get to the core, the stronger the pull. So, the closer to the center of gravity the stronger the more effect gravity would have opposed to farther away. Kind of like mass, the bigger something is the more gravity…

Researcher: Let me ask you this then, again, what do you think the relationship is when this force generated by the string is and the string generated by this (pointing to the weights).

Harold: They're constant.

Researcher: Are they equal or is one greater than then other. Is this force generated by the string greater than or equal the force generated by the weights.

Harold: At rest they're equal.

Researcher: Ok, when they are moving ….and when you say at rest, what do you mean at rest, when you say equal, how do you come to that conclusion.

Harold: Well, when they are no longer, no longer velocity, not moving up or down, their effect on the system would be equal.

Researcher: So, when I move this at constant speed, this needle is going to read one thing and when it stops, it's reading the same thing or something different.

Harold: It's reading the same.

Researcher: the same thing, so what conclusion could you draw from that.

Harold: That the forces, well I can't say the force is zero, cause I just said the force. I would say, base don that the forces were equal the whole time. But………

Researcher: the forces were equal the whole time.

Harold stated, after observing the event that "the measurement stayed the same….the measurement of the forces were equal but the momentum was not." He also stated that momentum was:

> *My idea of momentum is the effect, the effect of force in a horizontal or vertical direction as it reacts against weight and mass and any other force exerted. Momentum would be I guess, I don't want to say equivalent speed, but the direction and degree intensity in which an object is moving in any given direction in a 3d space.*

At this point, Harold maintained all of his prior conceptions.

Harold's interviews suggested that he brought four misconceptions to the research investigation (a) he was unclear about the relationship between the upward tension and downward weight force vectors, (b) he believed that force resulted in motion rather than in acceleration, (c) he was not sure about the meaning of acceleration, and (d) be believed that momentum and force were indistinguishable (see Table 6).

Phase III - The New Knowledge Activity

The researcher began the second phase by asking Harold to discuss his understanding of force, mass, velocity and acceleration:

Researcher: Let's talk about force. I want you to define force.

Harold: What force is?

Researcher: Yes, what force is. Whatever you know force to be.

Harold: Force for weight is the mass, it's a, it's not a component, it's a combination of acceleration and mass of an object.

Researcher: So how do you get force?

Harold: One of the two has to increase.

Researcher: If I were to ask you to calculate force, how would you do it. Given the mass and the acceleration how would you do it?

Harold: Multiply them by each other.

Researcher: What about mass, what is mass?

Harold: Mass is the amount of material, independent of weight, I mean independent of gravity.

Researcher: Ok, and then what is acceleration?

Harold: Acceleration is the magnitude of direction, combination of magnitude and direction, no I'm sorry, acceleration is not a combination. That's speed. Acceleration is a magnitude.

Researcher: It's a magnitude of what?

Harold: What is magnitude?

Researcher: No, you said it was magnitude. I'm wondering a magnitude of what?

Harold: A magnitude of …the…

Researcher: …it's how velocity changes, maybe.

Harold: Yeah, well, yeah…

Researcher: Divided by what?

Harold: What do you mean divided by?

Researcher: It's the change in velocity divided by…

Harold: ……time (doubtfully)…….

Researcher: Right, change in velocity divided by the time. Um, when we talked before we talked about an elevator and the relationship between the tension and the weight. If you're talking about the elevator accelerating up, what was your previous of what the relation ship between the tension and the weight. Do you remember what that was?

Harold: Previously? No…

Because Harold had not undergone conceptual change, the researcher attempted to engage Harold in an additional discussion related to the previous discrepant event:

Researcher: Can you tell me what your current understanding is. When it's accelerating up is the tension greater, equal to or less than the weight?

Harold: When, so you're talking about the part that's actually going up. When it's going up then the weight would be um…..there would be less of an effect on gravity, so…the weight would decrease cause the mass stays the same.

Researcher: So, what about the tension, how would the tension fit in?

Harold: It would be, well if it's going fast enough…..then at a point the tension would be less than. If the velocity was or if the acceleration overcame the acceleration of the string, then it would be less than.

Researcher: What about if it's traveling up at constant speed. Is the tension less than greater than or equal to the weight.

Harold: It's greater than cause it's got to over come the weight.

Researcher: What about if it's traveling down at constant speed?

Harold: Less than.

Researcher: What bout if it's accelerating down?

Harold: Less than.

Researcher: Let's look at the set up again. Just like before we have this set up that will simulate an elevator. The needle will represent the tension in the cable. What is it reading now?

Harold: 450 or 550, 560.

Researcher: So what I'm going to do is to accelerate us up by pulling on this string. So, you think that this is going to do what?

Harold: It should increase.

Researcher: That's not what you said before.

Harold: What did I say before?

Researcher: You said it was going to decrease.

Harold: The amount of force….

Researcher: Remember what I asked you before, what this is actually registering is the tension, so as I accelerate this up the question is, is the tension going to be greater than, less than or equal to the weight. Right now, they're equal because it's just registering the weight. But if I snatch this down when causes this to accelerate up is this going to increase or decrease.

Harold: Initially it's going to increase.

Researcher: Why do you say that?

Harold: Well then the whole thing would increase, because it has to overcome the weight of the object.

Researcher: Ok, let's see. When I pulled on it what did it do?

Harold: It increased significantly.

Researcher: Ok, it increased. So then, is the tension greater, less than or equal to the weight when something is accelerating up.

Harold: Greater than.

Researcher: Let's see what's going to happen when I go at constant speed. I'm going to allow this to move at constant speed and we want to see how the needle changes.

Harold: It doesn't change.

Researcher: It doesn't change, so when it's moving at constant speed going up what does it mean.

Harold: They're equal to the weight.

Researcher: They're equal. Let's see what happens with constant speed down.

Harold: It's less than???? No, they're the same.

Researcher: They're the same. And let's accelerate down. I'm going to jerk this down which is going to cause this to accelerate down. What's going to happen?

Harold: It should get lighter, ah less force.

Researcher: Let's see. Did it do that.

Harold: Yeah.

Researcher: So, let's review it again.

Harold: It's much harder to think about it and I'm actually looking at it.

Researcher: When something is accelerating up is the tension greater, less than or equal to the weight?

Harold: Greater than the weight.

Researcher: Accelerating down.

Harold: Accelerating down is less than.

Researcher: Constant speed up.

Harold: Same.

Researcher: Constant speed down.

Harold: Same.

Harold correctly knew that force was comprised of mass and acceleration. However, when the researcher asked Harold to describe acceleration, he responded that acceleration was a combination of mass and direction. Therefore, he was confused about acceleration. Finally, Harold stated that acceleration was the change in velocity divided by time, which was correct. After probing for Harold to elaborate, Harold doubtfully stated that the acceleration was change in velocity divided by time.

The researcher asked Harold to summarize his understanding of the relationship between tension and weight under positive, negative and zero acceleration. He replied that:

> *When it's going up then the weight would be um...there would be less of an effect on gravity, so…the weight would decrease because the mass stays the same…It[the tension] would be, well if it's going fast enough…..then at a point*

the tension would be less than. If the velocity was or if the acceleration overcame the acceleration of the string, then it would be less than.

Based on this discussion and the discrepant event, it appeared that Harold had not undergone conceptual change. He did not make the connection between positive acceleration and increased tension, nor between the negative acceleration and decreased tension.

The researcher and Harold continued to engage in conversation about the topic. Harold observed the discrepant event a second time. This time, the researcher spent more time on the portion related to constant speed. Harold observed (a second time) that the tension did not change under constant velocity. He concluded that the tension and the weight magnitudes were equal during constant velocity. Again, the researcher performed the discrepant event while demonstrating positive and negative acceleration:

Researcher: Let's look at the set up again. Just like before we have this set up that will simulate an elevator. The needle will represent the tension in the cable. What is it reading now?

Harold: 450 or 550, 560.

Researcher: So what I'm going to do is to accelerate us up by pulling on this string. So, you think that this is going to do what?

Harold: It should increase.

Researcher: That's not what you said before.

Harold: What did I say before?

Researcher: You said it was going to decrease.

Harold: The amount of force….

Researcher: Remember what I asked you before, what this is actually registering is the tension, so as I accelerate this up the question is, is the tension going to be greater than, less than or equal to the weight. Right now they're equal because it's just registering the weight. But if I snatch this down when causes this to accelerate up is this going to increase or decrease.

Harold: Initially it's going to increase.

Researcher: Why do you say that?

Harold: Well then, the whole thing would increase, because it has to overcome the weight of the object.

Researcher: Ok, let's see. When I pulled on it what did it do?

Harold: It increased significantly.

Researcher: Ok, it increased. So then, is the tension greater, less than or equal to the weight when something is accelerating up.

Harold: Greater than.

Researcher: Let's see what's going to happen when I go at constant speed. I'm going to allow this to move at constant speed and we want to see how the needle changes.

Harold: It doesn't change.

Researcher: It doesn't change, so when it's moving at constant speed going up what does it mean.

Harold: They're equal to the weight.

Researcher: They're equal. Let's see what happens with constant speed down.

Harold: It's less than???? No, they're the same.

Researcher: They're the same. And let's accelerate down. I'm going to jerk this down which is going to cause this to accelerate down. What's going to happen?

Harold: It should get lighter, ah less force.

Researcher: Let's see. Did it do that?

Harold: Yeah.

Researcher: So, let's review it again.

Harold: It's much harder to think about it and I'm actually looking at it.

Researcher: When something is accelerating up is the tension greater, less than or equal to the weight?

Harold: Greater than the weight.

Researcher: Accelerating down.

Harold: Accelerating down is less than.

Researcher: Constant speed up.

Harold: Same.

Researcher: Constant speed down.

Harold: Same.

Harold seemed to understand the concept this time.

Harold also revealed his definition of mass as the amount of material, independent of gravity, which was correct. Finally, the researcher asked Harold to describe his conception of acceleration. Harold's reply was:

> *Acceleration is the magnitude of direction, combination of magnitude and direction, no I'm sorry, acceleration is not a combination. That's speed. Acceleration is magnitude.*

His conception was partially correct, for acceleration is vector quantity which contains magnitude and direction. The researcher lead Harold to realize, though doubtfully, that acceleration was the change in velocity divided by the change in time.

The conversation moved on to focus on Harold's current understanding of the tension and weight relationship. His reply was:

> *When it's going up then the weight would be um…there would be less of an effect on gravity, so…the weight would decrease because the mass stays the same. It would be, well if it's going fast enough...then at a point the tension would be less than. If the velocity was or if the acceleration overcame the acceleration of the string, then it would be less than.*

When asked if the tension would be less than, greater than or equal to the weigh under upward constant speed, Harold indicated that it would be greater, because its got to overcome the weight. He incorrectly responded that the tension would be less than the weight if traveling downward at constant speed. After discussing the topic, Harold was still confused about the relationship between the tension and weight under the various kinematic motion descriptions.

The researcher attempted to lead Harold to the correct understanding. They performed the discrepant event again. Harold observed that the spring gauge's needle did not move while under constant velocity. He again informally predicted that while accelerating downward, the needle should deflect downward; this time he was correct. Harold also realized that positive acceleration resulted in increased tension. Harold commented that:

> *It's much harder to think about it and I'm actually looking at.*

When provided with the new knowledge exercise in which Harold was to identify the forces on the golf ball, Harold answered all questions correctly. His line of reasoning was the same for each of the exercises. Harold reasoned in terms of displacement rather than in terms of acceleration:

> *Even though its independent and one acts and the other one has to react to it and in this case the rocket accelerates and then the body reacts to this acceleration. So, when it fires all of a sudden the body is at rest for a second, a split second and the body has to catch up which happens by more force being exerted by x until it reaches a constant speed*

The researcher returned to the main topic of tension and weight. Harold stated that under constant velocity:

> *It would be, well if its going fast enough...then at a point the tension would be less than. If the velocity was or if the acceleration overcame the acceleration of the string, then it would be less than.*

Harold still maintained the misconception. The researcher suggested reviewing the discrepant event. When discussing the conditions of abrupt acceleration, Harold understood that the tension would increase. When the researcher allowed the system to move at constant speed, Harold observed that condition and correctly stated, "they're equal to the weigh." Thus, after discussing the discrepant event a second time, Harold seemed to understand, suggesting conceptual change. However, Harold's posttest score was unsatisfactory because he chose the incorrect response.

Harold was an inquisitive student in which many of his questions reflected his inquisitiveness. His questions were often more akin to "why" things worked than to “what” worked, thus reaching for the fundamentals of physical reality. He demonstrated repeated attempts to extend his understanding beyond the connections of mathematical models to concepts. In a sense, Harold was attempting to accommodate the new concepts of the class into his existing conceptual framework.

Though successful with other concepts, these attempts were unsuccessful when attempting to make sense of the concept under review. Initially, Harold believed that the upward force of the tension exceeded that of the weight vector. At the conclusion of the study Harold maintained the same conception as based on the results of the.

On several instances, Harold attempted to assimilate new concepts. At the start of the discrepant event, the researcher asked Harold about his understanding of the relationship between the tension and the weight. He stated that:

> *Well, it’s generating force because it’s in contact with that, but the string, the strength, the amount of weight the string can handle is based on the other weights. So, if the string had no weights to counter balance it, then the string would have and effective force of zero.*

Thus, Harold was unclear about that relationship, which is consistent with his pretest score.

At the conclusion of the discrepant event, the researcher asked Harold about his idea of the relationship between the tension and the weight under constant speed. His response was, “that but that the strength of the string is based on other weights. He understood that the other weights influenced the tension. However, he tried to assimilate that information into his knowledge structure and was unsuccessful.” When asked about the forces acting on the system at constant speed, again he assimilated the information, insisting that momentum was a “force.”

Harold responded correctly to all new-knowledge questions (see Figure 4):

Researcher: So, that’s it. Let’s talk now about the exercise that I gave you. Now, the first one. Rocket #1 is going to fire. Tell me what your answer is.

Harold: X is going to be greater than zero Newtons and y is going to be equal to 100 Newtons.

Researcher: How did you get that?

Harold: Assuming that I read this right, as it fires forward the initially acceleration for the upper part of y our body which is resting against the x is zero. And the acceleration of the object is zero, but then the object is accelerating so your body has to catch up with acceleration of the object. So, initially it’s greater than zero Newtons.

Researcher: Now let’s look back at that rocket. The first example, if you fire Rocket #1 what did you get.

Harold: X is greater than zero Newtons.

Researcher: and what about y

Harold: it’s equal to 100 Newtons.

Researcher: How did you get that.

Harold: There’s no change in the y direction so the y should stay the same. The mass times the acceleration doesn’t change. It’s a constant. The way for the x that I look at it is even though there’s an object inside this object they’re not, if they both start from rest then there both moving at zero.

Even though it's independent and one acts and the other one has to react to it and in this case the rocket sudden the body is at rest for a second, a split second and the body has to catch up which happens by more force being exerted by x until it reaches a constant speed until…..

Researcher: How does that that example (rocket example) and this (demonstration) relate.

Harold: Because……

Researcher: First off, do they relate?

Harold: Well, yeah, if you look at it like that then when that's going down the tension is going up and the tension is represented by x.

Researcher: Let's look at the second one.

Harold: The second one I said that Rocket #2 is going to be equal to zero Newtons because there's no change in the x direction and the y is going to be greater than 100 Newtons because if you look at like this, as the whole object is moving up so your body is independent and so when it moves up it takes a second to reach and since the acceleration is upward the body is reacting technically in a downward which is going to create more force.

Researcher: Three.

Harold: Less than zero Newtons for X and equal to 100 Newtons for y. There's no change in the y direction so that's why the y direction stays at zero. X is at zero Newtons your body, the direction that the object will be moving will be opposite of the body's position to the x, whatever. So, the whole thing actually moves back…

Researcher: ….accelerates back…..

Harold: …accelerates in a negative x direction. And so the body will have to catch up.

Researcher: Four.

Harold: X is equal to zero Newtons because there's no movement…

Researcher: …no acceleration……

Harold: …no acceleration and y is less than 100 Newtons because the acceleration for that direction is in the negative y direction which means that the object will be moving further away from the body so the mass times the acceleration of the body will have to catch up to with it.

Researcher: What about five?

Harold: I said that x is equal to zero Newtons, that's not right and y is equal to 100 Newtons. Oh, yeah that's right, because they both are equal force and magnitude going in opposite directions so they cancel each other out.

Researcher: So, what's the acceleration.

Harold: Zero.

Researcher: What about six.

Harold: For Rockets #1 and #2, X is greater than zero Newtons and y is greater than 100 Newtons.

Researcher: So, the acceleration is going to be in what direction.

Harold: In the….uh….45 degree angle.

Researcher: Ok, number seven.

Harold: X is less than zero Newtons and y is less than 100 Newtons.

Researcher: Acceleration would be in which direction.

Harold: They would both be negative.

Researcher: Finally, let’s look at number eight.

Harold: Moving at constant speed. Well, moving at a constant speed, although I have greater than zero Newtons, well x is greater than zero Newtons and y is equal to 100 Newtons. That’s wrong. They’re both going to be equal to 0 and 100, respectively.

Researcher: So, which will be zero. What will x be?

Harold: Well, I said that greater that zero Newtons. But if it’s a constant speed, they’re both going to be the same. And what that value is going to be, whether it’s zero or not, I don’t know…

Researcher: If they start out x starts out at zero and y starts out at 100. So, what is the x going to read while this is moving at this speed here (constant speed).

Harold: Well, if it’s constant it’s going to read, well whatever the difference the 100 m/s makes, but it’s not going to change.

Researcher: So what’s it going to read.

Harold: Uh, what ever the mass is times 100.

Researcher: Why is that?

Harold: Mass times 100 times force.

Researcher: What’s the acceleration.

Harold: One hundred m/s, uh, there’s no acceleration. Yeah, it’s going to be zero.

Researcher: Ok, so the acceleration is what now.

Harold: Zero.

Researcher: So what's the X reading.

Harold: It's going to read just it's mass, uh its force. Acceleration is zero, so it's going to read zero.

Researcher: And what's the y going to read.

Harold: Uh, it's going to read 100.

Researcher: So what causes the x and y to change is what.

Harold: Movement, uh, no, acceleration for x and a negative for the x direction.

Researcher: You said it correct, it's the acceleration.

His response repeatedly included references to "going" rather than to "accelerating." His understanding is

> A*s the whole object is moving up your body is independent and so when it moves up it takes a second to reach; and since the acceleration is upward the body is reacting technically downward which is going to create more force.*

Harold was able to determine the correct answers to the new-knowledge questions; however, he got all the "right" answers for the "wrong" reasons – not fully understanding the concept of acceleration. Without this crucial understanding, conceptual change was difficult.

Harold struggled from the beginning of the investigation with understanding the concept for he often responded to a question with another question, signaling his confusion of the topic. When asked to formulate a conclusion regarding constant speed after the discrepant event, Harold stated that, "…the forces were equal the whole time." However, he stated that, "…the effective relation of the momentum was not." He indicated that momentum was equivalent to speed. Thus, Harold often utilized terms for which he was unsure in an attempt to “explain away” the results of the discrepant event. This, according to Meyer (1993) suggested that Harold resisted changing conceptions, thus treating contradictions as irrelevant. Again, after the discrepant event, the researcher asked Harold for his current understanding of the concept. His response was, “…When it’s going up then the weight would be um...there would be less of an effect on gravity, so…the weight would decrease because the mass stays the same.”

Phase IV - Conceptual Change Strategies

These latter statements revealed that Harold had not accepted the concept as intelligible or plausible nor fruitfulness. Harold’s posttest response was incorrect, believing that an elevator moves upward at constant speed only because of a shortened cable and not because of the force exerted on the cable.

Harold did not indicate any instances of metacognitive awareness. However, he did utilize evaluation (see Table 3). During the first instance, the researcher asked Harold to review his current understanding of the concept. He indicated that, “it’s much harder to think about it and I’m actually looking at it.” This comment suggested that Harold was thinking hard about the concept, attempting to assimilate the new knowledge into his existing conceptual framework.

The next instance served as both the metacognitive of evaluation and reflection (see Table 2). Here, Harold discussed the answer to number seven and eight in the new knowledge activity that was related to a rocket moving at constant speed:

Researcher: Ok, number seven.

Harold: X is less than zero Newtons and y is less than one hundred Newtons.

Researcher: Acceleration would be in which direction

Harold: They would both be negative.

Researcher: Finally, let's look at number eight.

Harold: Moving at constant speed. Well, moving at a constant speed, although I have greater than zero Newtons, well x is greater than zero Newtons and y is equal to one hundred Newtons. That's wrong. They're both going to be equal to zero and one hundred, respectively.

After providing the incorrect answer, he thought about the answer and commented that, "…that's wrong." Further, he responded that, "they're both going to be equal to zero and one hundred, respectively."

Harold completed all regular math and science courses in high school; in addition he competed AP calculus. He stated that his struggle with understanding the concept involved his inability to visualize the concept. He stated that, "Once I physically see some model for it, it was a lot easier to understand." Harold quantified his struggle at 4 out of 10 (see Table 5). His assessment of his understanding was:

> *I knew the forces involved, and I could tell what equations it was based on but I didn't always get the right sign with the right component. … I guess the execution [the method used to solve the problem] was off.*

When asked to complete the posttest, Harold selected the incorrect response to the question associated with the Elevator misconception. Thus, Harold did not successfully undergo conceptual change.

Phase I - Acknowledgment of Understanding – Isaac

Isaac was a 22-year-old African-American male studying computer engineering. His high school GPA was 3.0/4.0 and his college GPA was 2.0/4.0. Isaac completed regular level physical science, Algebra I and II, geometry, trigonometry and calculus in high school. As of this writing, Isaac's standing in Physics I was 64%. Isaac's FCI response was selection "a," the upward force on the elevator by the cable is greater than the downward force of gravity.

The initial discussion with Isaac began with a discussion of his understandings:

Researcher: Let's say that you had an elevator and this elevator was demonstrated with tension up and the mg down. And this elevator is going to move up a shaft at constant speed. The question is what is the relationship between the tension and the mg? Is the tension greater than, less than, or equal to the mg if it's moving upward at constant speed?

Isaac: The tension would be greater than the mg, I believe…….

Researcher: And why do you believe that?

Isaac: Because the force is acting up and that is more strain on the tension, right.

Researcher: Now, what about if it is moving up and acceleration upward, what would the relation between the tension and the mg?

Isaac: I still believe that the tension would be greater than the mg.

Researcher: Ok, and what about if it is moving downward at constant speed, what would the relation be between the tension and the mg.

Isaac: I believe that mg would be greater but at the same time I see that,……I believe that the tension would greater now because if it's moving now that means more strain on the tension to keep it stable.

Researcher: And if where accelerating downward, meaning the velocity would be increasing downward, how would the tension and the mg be?

Isaac: For some reason, I want to say that the mg would be greater.

He believed that under constant speed, the magnitude of the tension would exceed that of the weight; that negative acceleration would result in tension greater than the weight magnitude; downward motion at constant speed would result in a greater weight and finally a negative acceleration would result in a greater weight than tension.

Phase II - Collecting Evidence

The researcher introduced the discrepant event to Isaac, asking for his predictions under the differing conditions:

Researcher: Alright, now what we're going to do…I have this set up and the it is going to represent an elevator. This will be the tension here, (pointing to the upward arrow) and this will be the mg. And the mg will be demonstrated by the scale her. So what I'm going to do is….. you have three slots here, actually four….so what I want you to do is to (explaining the 4 cases with a=0 up and down, and a=/ 0 up and down)…So, I want you to write her what the tensions would be…….(demonstrating)…..Ok, we're going to see what actually happens, with constant speed upward and constant speed downward. First, what is this thing actually reading?

Isaac: 554 grams.

Researcher: Ok, 554 grams. So, I'm going to move this thing upward and I want to find out how this needle is going to change. (demonstrating). Is it moving…..

Isaac: It stayed the same.

Researcher: Ok, so now we're going to go down at constant speed (demonstrating)

Isaac: Stayed the same.

Researcher: So what's the conclusion, then?

Isaac: At the tension and the mass times gravity, would stay the same.

Researcher: What's the relationship between them if this thing is moving at constant speed.

Isaac: Stay the same…

Researcher: Ok, now, just hold onto that thought, what you seem to be saying is that the relationship between the tension and the mg are the same at constant speed.

Isaac: Yes, sir.

Researcher: Now, what I'm going to do is to accelerated this thing downward…..I'm going to pull on this string and allow it to accelerate upward and let's see. Now, you said that the tension is going to do what.

Isaac: That the tension is…..the mg will be greater.

Researcher: The mg will be greater when it's accelerating down. So, if it gets greater, then what should the needle do, go up or down?

Isaac: It should go down.

Researcher: Ok, when it accelerates down, let's see…..(demonstrating)…see that…..

Isaac: It went up, so the tension was greater than mg.

Researcher: So, well, wait a minute, when this….the tension increases that goes down (demonstrating), do we're trying to figure out what the tension is here. So, when I accelerate this thing down, you said what now…

Isaac: The mg would be greater than the tension.

Researcher: So what does that mean as far as the tension?

Isaac: That means the mg would go up, right,

Researcher: And that is what happens…so that means that the tension is going to be less than or the mg would be greater than. And what you're saying is right…..so what about when I accelerate it up.

Isaac: The tension would be greater.

Isaac predicted that the tension would be greater than the weight under upward constant velocity and upward acceleration; he further predicted that the weight would exceed the tension under downward constant velocity and downward acceleration. Upon observing the discrepant event, Isaac realized that half of his predictions were incorrect.

Researcher: Let's see. When I accelerate it up, what happens?

Isaac: It went down….

Researcher: Meaning what?

Isaac: The tension is greater than…

Researcher: So, write those things down. Now, tell me what you learned….what you learned, what you believed, and what you now believe and what brought about the difference.

Isaac: Basically, I just found out that when the acceleration equals zero in either the tension or the mg direction, basically, I'm saying, they stay the same force. I don't know the words to say.

Researcher: Are the tension and mg equal under constant velocity.

Isaac: They are equal.

Researcher: When this thing is accelerating upward and downward, is that your understanding.

Isaac: When it's not accelerating….

Researcher: OK, when it's not accelerating. And when it's accelerating up, which one is greater, the tension or mg.

Isaac: When accelerating up, the tension.

Researcher: And when it's accelerating, which is greater, the tension or the mg.

Isaac: The mg.

Researcher: So, if you get on an elevator and you were to place a scale in the elevator, and you weighed 150 pounds and stood on the scale, what would the scale read when the elevator is moving at constant speed.

Isaac: Uh, 150 pounds.

Researcher: What about when it's accelerating upward. Would the scale read more than, less than or equal to 150 pounds.

Isaac: Um……more than the 150 pounds.

Researcher: Ok, what about when the elevator is accelerating downward, what would the scale read, more than, less than or equal to 150 pounds?

Isaac: (thinking)…..less than 150 pounds.

Researcher: Ok, that's what I needed to get. Thanks…

His comment was:

> *Basically, I just found out that when the acceleration equals zero in either the tension or the mg direction, basically, I'm saying, they stay the same force. I don't know the words to say.*

Isaac's understanding was that the tension and weight stayed the same when moving at constant velocity in either direction. He said that he predicted incorrectly because he did not account for the acceleration.

In summary, Isaac began the research investigation with two misconceptions: (a) he did not understand the relationship between the opposing force and acceleration; (b) Isaac believed that force created motion rather than acceleration; and (c) he was not clear about the concept of acceleration (see Table 6).

Phase III - The New Knowledge Activity

Isaac's second phase began with a discussion of his conception of velocity, force, mass and acceleration:

Researcher: Let's talk about force and what your idea is.

Isaac: Force is basically, it's hard to put into words….but I'd say something acting on something else to get it to move.

Researcher: How do you calculate force, what is required to calculate force, what two things do you need to calculate force?

Isaac: Mass times acceleration.

Researcher: What is acceleration?

Isaac: Acceleration is not…..it's…..I know exactly what it is but it's hard to put it into words. It's not something moving fast and in the direction but it's acting on something else to cause it to accelerate.

Researcher: But what's happening to the velocity.

Isaac: Velocity usually speeds up.

Researcher: So you have a change in velocity divided by what……

Isaac: the change in velocity divided by…….

Researcher: …..think about the units. What are the units for acceleration?

Isaac: Mass over seconds squared.

Researcher: Meters over seconds squared.

Isaac: Meters over seconds squared.

Researcher: So it's the change in velocity divided by time.

Isaac: Exactly.

Researcher: So, you already said that with force, you have to have acceleration and mass. What do you do with those two to get force?

Isaac: To get the sum of the forces you have to multiply those two together.

Researcher: Multiply force and acceleration together. Tell me what mass is.

Isaac: Mass is basically, what's taking up space, I don't want to say weight or, basically, a simple definition is that anything taking up space.

Isaac stated that, "force is something acting on something else to get it to move." Isaac correctly stated that the product of mass and acceleration comprised force. However, he struggled with the definition of acceleration:

Acceleration is not…it's I know exactly what it is but It's hard to put it into words. It's not something moving fast and in the direction but it's acting on something else to cause it to accelerate.

When the researcher asked further about acceleration, Isaac was not able to answer the question. The researcher moved on to the notion of mass. Isaac stated that mass was "what's taking up space."

The next phase of questioning centered on Isaac's conception of the relationship of the tension force to the weight force. He doubtfully stated that:

When accelerating up, I think the tension would be greater when going up…

When the researcher again performed the demonstration, Isaac correctly stated that the upward acceleration would result in increased tension; when it underwent a negative acceleration, the tension decreased and at constant speed, the tension did not change.

The researcher administered the new knowledge activity. Isaac correctly responded to all questions on the activity (see Figure 4):

Researcher: Let's talk about this example with the rocket. I want you to…..let's talk about the firing of the rockets. Tell me what your answers were. If you fire rocket one, what are your answer to x and y direction.

Isaac: Basically, firing rocket one, x would be greater than zero; basically because if it is firing this way, more pressure is going to go this way against the seat, so I put x would be greater than zero.

Researcher: And what about y.

Isaac: Y, I though it was all together, y would be equal to one hundred Newtons.

Researcher: And why did you come up with those answers.

Isaac: Basically, you're firing rocket, he's going to impale into the seat and that's going to cause x to be greater than zero. And y would stay the same because that's where he's staying.

Researcher: Let's talk about two. Tell me what your answers were and why you chose them. If you want to change them that's ok. Tell me about two.

Isaac: Rocket #2, I put x equals zero and y would be greater than 100 Newtons. Because, rocket two firing up that's going to put force on the seat and that's going to cause y to be greater than zero because that's putting him into it and x would be zero because it's not in the same direction. If Rocket #2 fires he's going down like that.

Researcher: So, tell me again what your answer is for x.

Isaac: X would be equal to zero and y would be greater than one hundred.

Researcher: Let's look at number three.

Isaac: I got x equals to zero and y equals to, I don't got anything for.

Researcher: Ok, so you're saying that for three, x is going to be equal to zero and y is going to be what?

Isaac: I didn't have anything but it would have to be equal to one hundred Newtons.

Researcher: I agree with that.

Isaac: I did mess up because I took it that once it fires he comes out of the seat unless he is strapped in.

Researcher: Let's talk about firing Rocket #4.

Isaac: X equal zero Newtons and y is less than 100 Newtons.

Researcher: Let's go to number five. You're going to fire Rocket #1 and #3.

Isaac: Ok, first x would be greater than zero and I was just marking one, X would be greater than 100 Newtons.

Researcher: Tell me how you got that.

Isaac: Basically, if one is firing it's putting him in the seat.

Researcher: Which way is one firing?

Isaac: It's firing, I'm taking, once it's firing, I'm taking that once it's firing it going that way

Researcher: Ok, but look one and three are firing at the same time.

Isaac: Oh, hold up, matter of fact, I messed up, I was talking about another one, but if y equals to one hundred Newtons and basically x is I'm saying equal to one hundred Newtons.

Researcher: And why is x equal to zero.

Isaac: Basically because both of them is firing at the same direction and he's not going to move on the x direction.

Researcher: What about six

Isaac: One and two, basically I got x is zero Newtons and y is greater than one hundred Newtons.

Researcher: Why is that?

Isaac: Because one is impaling him into the seat and the other is impaling him back.

Researcher: What is impaling?

Isaac: I mean, one is…

Researcher: ….you mean accelerating.

Isaac: …..accelerating.

Researcher: So, then what is the rocket going to do in six. You have one and two firing. What way is the rocket going to accelerate?

Isaac: It's not going to accelerate.

Researcher: Not going to accelerate if you fire one and two together.

Isaac: It's going to be at an angle upward, like 45 degrees.

Researcher: Let's look at number seven, three and four.

Isaac: Three and four, I got x equals to zero and y equals less than one hundred Newtons.

Researcher: And let's look at eight.

Isaac: Eight, I got x is greater than zero Newtons and y is equal to one hundred Newtons.

Researcher: Tell me why x is greater than one hundred Newtons.

Isaac: Because, matter of fact, x is equal to zero.

Researcher: Why is that?

Isaac: Because it has no acceleration and y is equal to one hundred Newtons

Researcher: Why is that?

Isaac: Basically because it's not accelerating.

Researcher: If I were to ask you to calculate, like in number six in which you fire two rockets, if rocket one and two were firing, if I ask you to calculate the magnitude of the acceleration how would you do that?

Isaac: By solving the forces in both directions…

Researcher: And then do what?

Isaac: Set them equal to the mass times the acceleration.

Researcher: So you said a minute ago that you'd get a 45 degree angle. How is that?

Isaac: Basically, if was more or less common sense with me. But it's like, both of them is firing from a 90 degree angle and it's going to cause a 45 degree angle.

Researcher: Would there be more than one way to solve the problem

Isaac: I believe there would.

Researcher: Do you have any idea how?

Isaac: …….(thinking)…..you would have to draw a free body diagram, that's one way or it's something with sine and cosine of the angle.

Researcher: Do you think that your answers are correct.

Isaac: Yes sir.

Researcher: Why do you think your answers are correct?

Isaac: I just believe I'm right.

Isaac was asked to identify the forces resulting from the firing of rocket one. He responded that:

… firing rocket one, x would be greater than zero; basically because if it is firing this way, more pressure is going to go this way against the seat, so I put x would be greater than zero.

However, posttest score related to the conceptual change was incorrect.

Phase IV - Conceptual Change Strategies

Isaac responded correctly to all questions. After the administration of the discrepant event, he correctly concluded that, "… when the acceleration equals zero in either the tension or the mg direction…they stay the same force." Further, he correctly indicated that when accelerating upward, the tension exceeds the weight; when accelerating downward, the weight exceeds the tension. Thus, during the investigation, Isaac comprehended the concepts as being intelligible (see Table 2). Even during the second phase as well as in answering the new-knowledge questions, he again, provided the correct responses to all questions. However, when asked if he thought that his answers and that this concept was correct, Isaac merely responded that, "I just believe that I'm right." Because he provided no basis for his ideas, it is doubtful that Isaac thought that the new concept was neither plausible nor fruitful. Isaac's posttest score mirrored that of his pretest score for Question #18 – he believed that the tension exceeded the weight during constant speed.

Isaac demonstrated no instances of metacognitive awareness (see Table 3). The strategies of evaluation and reflection jointly surfaced twice. The first time, Isaac utilized evaluation/reflection while discussing the answer to the third new knowledge activity. Isaac's response was initially incorrect. His follow up comment was that, "I did mess up because I took it that one it fires, he comes out of the seat unless he is strapped in." The second instance was similar in which he corrected an incorrect comment. He said that, "I messed up….if y equals 100 Newtons and basically x is I'm saying equal to 100 Newtons."

Isaac did not undergo conceptual change. He completed regular level physical science as well as regular level math courses, but had no physics in high school. He quantified his struggle at 4 out of 10 (see Table 6). Isaac stated that he struggled with understanding the relationship between the upward tension and the downward weight vector positive, negative and zero acceleration; the hard part was:

> *it's once you have to actually put in a formula it's easy to be like the sum of force equals mass times the acceleration if it's centered like centripetal force how you set it perpendicular. But, paying attention to like the sine of 30 degrees, just plugging it in is the hardest part for me.*

When asked to complete the posttest, Isaac selected the incorrect response to the question associated with the Elevator misconception. Thus, Isaac did not successfully undergo conceptual change.

Phase I - Acknowledgment of Understanding – Jack

Jack was a 25-year-old White male studying construction. Jack listed his high school GPA as 3.0/4.0 and his college GPA as 2.4/4.0. He completed regular level Algebra I and II, geometry and trigonometry in high school. As of this writing Jack's academic standing in Physics I was 46%. Jack's response to Question #18 on the FCI was as follows: he believed that the upward force of the tension is greater than the downward force of the gravity.

Researcher: One of the questions was on the pre test was this? "An elevator is being lifted up an elevator shaft at constant speed by a steel cable. When the elevator is moving at constant speed…" the question was what is the relationship between the upward tension vector and the downward weight vector. The answer that you supplied is that the upward force of the tension is greater than the downward force of the gravity. Here is a representation of the diagram. What we're looking at is a diagram of the elevator with a tension upward and an mg vector downward. This elevator here is accelerating; no let's look at constant speed. What is the relationship between the tension and the mg vector?

Jack: Shouldn't the tension be higher than the weight to make it go up?

Researcher: Ok, I won't be giving you the right answers. I'll just be listening.

Jack: So, tell my why you believe that. Well, the tension wasn't…. if it was not as much as the weight, then it would break, right. I mean, that's what I would think.

Researcher: And what about when this is moving upward at constant speed, what is the relationship between the tension and the weight.

Jack: It's accelerating upward, I would think that it would, it's moving constantly up, right…..

Researcher: ….well constant velocity, I'm sorry, constant acceleration, the velocity is changing.

Jack: Um…I would think the same thing. The tension on the cable would be pretty high than the weight to handle it.

When asked to justify his answer to the FCI, Jack asserted:

Well, the tension wasn't…if it was not as much as the weight, then it would break, right. I mean, that's what I would think.

Jack incorrectly understood that under constant velocity, the tension on the cable would exceed that of the weight. He also incorrectly understood that downward acceleration would result in a greater tension. Thus, in each case, Jack's expectation is that the tension would exceed the weight.

Phase II - Collecting Evidence

The researcher asked Jack to predict the behavior of the Atwood Pulley under three conditions: under positive, negative and zero acceleration.

Researcher: Let's look also that if this elevator were moving downward at constant speed, what would the relationship be between the tension and the weight?

Jack: Probably the same thing. The tension on the cable would have to be pretty high. If not I would believe that that the cable would break.

Researcher: OK, then what about when the elevator is accelerating downward. What is the relationship between the tension and the weight.

Jack: I would say the same thing. The same going up and down, it's just reversed.

Researcher: So then you’re thinking that when it’s accelerating downward, you think that the tension has to be greater than the mg.

Jack: I would think so…

Researcher: And when its accelerating, the tension is greater than the mg.

Jack: Yes.

Jack observed the discrepant event and made the following comments:

Researcher: What we’re going to do is to allow this to move upward at constant speed and see how the needle changes and allow it to move upward with acceleration and see how the needle changes. Then we’re going to allow the system to move downward at constant speed and watch the needle…then allow the system to accelerate downward and watch the needle. So, we have 4 scenarios…What we’re going to do is to work this system and see what happens. Now, what is this reading?

Jack: Five hundred grams

Researcher: I’m going to give this a gentle tug and we’re going to see what happens to the needle. With this moving at constant speed, what is happening to the needle? Is it changing?

Jack: No, it’s not changing.

Researcher: So, when moving at constant speed, has the needle changed?

Jack: It hasn’t changed.

Researcher: Then at constant speed, what is the relationship between the tension and the weight?

Jack: It's the same.

Researcher: So, you need to write that down …..So, let's see what happens when I accelerate this upward by pulling on this string. What did you say would happen to the tension?

Jack: It would go higher.

Researcher: Let's see. Did it do that?

Jack: Yes, it went higher.

Researcher: So that when I pull on this and it accelerates up the tension goes…….

Jack: It goes higher almost to eight hundred.

Researcher: What about when I accelerate downward what happens?

Jack: I think it's going to go up too, but maybe now it's going to go down (watching the demonstration). So, now it's going down in the other direction.

Researcher: So, when it accelerates down, the tension does what?

Jack: The tension goes down.

Researcher: And when it accelerates up the tension does what?

Jack: It goes up.

Researcher: I need for you to write those things down…..So what you said is that you see that there's a difference between your prediction and what actually happened.

Jack: That's correct.

During the demonstration of the discrepant event, Jack noticed that both upward and downward constant velocity resulted in no change of the tension and weight. He looked puzzled and merely said, “It hasn’t changed.” He also noticed that the tension was greater when encountering a negative acceleration. When asked to elaborate on his prediction before observing the demonstration, Jack said. “I think it’s going to go up too, but maybe now it’s going to go down.” At the completion of the discrepant event, Jack attributed the difference between his predictions and the outcome to not considering the effect of acceleration on the system.

In summary, Jack’s initial misconceptions were associated with: (a) relationship of opposing forces and acceleration and (b) definition of acceleration.

Phase III - The New Knowledge Activity

The second phase began by reviewing the Jack’s understanding of the relationship between the positive tension vector and the negative weight vector under positive, negative and zero acceleration:

Researcher: Now when we talked about the first interview, we talked about the elevator. Do you remember?

Jack: Yep.

Researcher: Do you remember the concept that we talked about?

Jack: We talked about the tension, the weight, and all coming down.

Researcher: So, we were talking about the relation between the tension and the weight going down under four different conditions: acceleration and constant velocity up and down. Explain to me the concept before we began to talk.

Jack: When the weight was going down the tension was going down, it was not as much. And then when the weight was going up the tension was more, I think.

Researcher: Let's talk about accelerating up. Do you remember your previous understanding when the mass was accelerating up.

Jack: I think I said that when the weight was going up the tension was less than when it was going down.

Researcher: What about when it was constant?

Jack: Constant velocity, I think I was wrong at first; I think I said it was going up too. I don't remember exactly. I know now it was not.

Researcher: Explain it as you understand it under those four conditions.

Jack: I know now that when the weight is going up and the mg is going down the tension is less and the weight is less.

Researcher: This is under which condition.

Jack: When the weight….

Researcher: Acceleration or constant speed.

Jack: Down. Well the weight is going down. That one is going up and that one is going down (the mg). When that one is heading up and that one is heading down the tension is less. And the tension is going down and the weight is going to be more, that's right.

Researcher: What about when you have constant speed going down.

Jack: When it's constant speed going down the weight is the same and the tension…….

Researcher: ……as what…..

Jack: …as, when it's constant, it's going up (frustrated)…..when it's constant speed going down the weight stays the same across the whole range and tension stays the same; it doesn't go up or down. Right…I think that's right.

Jack correctly stated his understanding of those concepts, though he sounded as if he was merely reciting from rote memory rather than demonstrating deep comprehension. Probing Jack's understanding of the concepts confirmed the suspicions; he really did not comprehend the concepts and was just repeating information from memory. Thus, the researcher drew diagrams in an attempt to help guide Jack to the correct understanding of the concepts. He demonstrated that he was moving toward the correct concept with this comment:

> *Your weight is not going to change regardless. You're going to weigh the same no matter what, but momentarily, your normal force will change because I guess, you're overcoming.*

The final phase focused on Jack's responses to the new knowledge activity (see Figure 4):

Researcher: Let's talk about the exercise that I gave you. Let's talk about your answers. You're given a rocket. Rocket #1 is going to fire and what is going to happen.

Jack: I think that the x is going to be greater than zero because you're going to be pushed back in your seat as you go. You're being propelled forward and the y your going to be equal, your weight is not going to change because you're going in the positive x direction.

Researcher: Ok is your weight changing.

Jack: Well, no.

Researcher: What's changing?

Jack: The acceleration, your accelerating, your velocity, now you're moving faster.

Researcher: Your velocity is increasing but is your weight actually changing.

Jack: No.

Researcher: If you actually weighted 170 pounds and your sitting in a rocket, is your weight going to change.

Jack: No.

Researcher: It's not going to change, but the reading on the scale will change because of what…..

Jack: …..because of acceleration.

Researcher: Right, and the acceleration along with the mass equals what……

Jack: …..acceleration ….

Researcher: A mass times acceleration equals what. Multiply mass and acceleration and you have a …

Jack: …..a……

Researcher: A force…

Jack: yeah, yeah oh yeah.

Researcher: Let's look at Number two.

Jack: In the x direction you're going to be less than zero because your going , your heading up so you're not going……

Researcher: …..accelerating……

Jack: …..accelerating in the positive y direction. So, you're going to be less than zero Newtons on the x an on the y it's going to be greater than 100 because you're accelerating up.

Researcher: Let's talk about the x direction. Tell me how you came up with that answer. You said it would be less than zero Newtons.

Jack: I should have said equal to.

Researcher: Ok, equal to…

Jack: It should be the same, you're not getting pushed forward or backwards so,

Researcher: Let's look at Number three.

Jack: Three is coming in the negative x direction now so…

Researcher: …accelerating in the x direction…..

Jack: …accelerating in the negative x direction. You're going to be equal to zero because you're not pushing up, I think. You're pushing, it's , your going to the left…..

Researcher: ….accelerating to the left…..

Jack: …accelerating to the left. I have a problem with that. You're accelerating to the left and equal to zero Newtons and in the y you're going to be equal to 100 Newtons. You're not accelerating up or down, your accelerating in the negative x.

Researcher: And Number four?

Jack: Accelerating in the negative y direction so you're going to be less than zero, I don't know if that' right.

Researcher: Why don't you think that's right.

Jack: I think you should be equal to.

Researcher: If you're in the x direction.

Jack: Yes.

Researcher: Why do you think it would be equal to?

Jack: Because you're accelerating in the negative direction, not accelerating in the x direction, you're accelerating in the negative y direction. So, you should be equal to.

Researcher: Ok.

Jack: Then in the y direction you're going to be less than 100 Newtons because momentarily you're going to weigh less.

Researcher: Going to weigh less.

Jack: Your mass would be less, right.

Researcher: Well, if you weigh 170 pounds and you sit in a rocket and accelerate down, is your weight going to change.

Jack: No.

Researcher: So what's going to change?

Jack: Your weight.

Researcher: No, not your weight. What is the scale actually recording . It's recording the normal force, right.

Jack: Right.

Researcher: So, then…..

Jack: If you're accelerating in the negative y direction, your normal force will momentarily be less,

Researcher: Right.

Jack: So, you catch up with it.

Researcher: That's what changes; the normal force changes not the weight.

Jack: Your weight is not going to change regardless (forcefully and convinced). You're going to weight the same no matter what, but momentarily, your normal force will change cause I guess, you're overcoming.

Researcher: There's inertia. Remember we talked about it. Can you describe it?

Jack: Like when you're sitting and all of a sudden I'm pushed forward. Isn't there a moment of inertial?

Researcher: Well, no, there is a moment of inertia but that's a different thing. Inertia is just the resistance to change. Just like….

Jack: That thing is not wanting to go but you're making it go so all of a sudden it's…..is that right?

Researcher: Remember, we're talking about inertia and this does not want to move. If I pull on this is going to resist. The same is true when it's accelerating down.

Jack: So, once it catches up it goes back to its original.

Researcher: Let's go on and talk about firing Rockets #1 and #3.

Jack: It's not going anywhere…

Researcher: ……it's not accelerating……

Jack: It's not accelerating. It's firing both out of the positive and negative x direction. And then y you're still equal the weight.

Researcher: And firing Rockets #1 and #2.

Jack: Accelerating in the positive x and positive y so you're greater than and positive in the x and greater than one hundred in the y.

Researcher: Seven, firing Rockets #3 and #4.

Jack: Firing three and accelerating in the negative x direction, so that would be less than zero Newtons; firing rocket four would be in the negative y direction so it would be less than 100 Newtons. The weight momentarily would be less.

Researcher: And the last one.

Jack: Eight, constant speed should be equal in the x direction and equal to 100 in the y direction.

Researcher: That sounds good

Jack provided the correct answers to all questions except Question #2. He stated that when rocket #2 was fired, the x value would be less than zero Newtons. The researcher reinforced the concept with the discrepant event, hoping that Jack would connect those concepts to the new knowledge activity. He changed to the correct answer after conversing with the researcher.

Jack struggled with understanding the relationship between the tension and weight vectors under positive, negative and zero acceleration from the very beginning of the investigation. However, after the discrepant event, Jack stated that, "…just like the experiment showed, it's going to stay the same." Jack was correctly referring to the tension under constant velocity. He also correctly concluded that the tension increases under positive acceleration and that the tension decreases under negative acceleration. Another statement that confirmed his understanding was, "…your weight's wanting to go down and you're going up and you're pushing against the scale." Jack was unaware of this but he was describing inertia. Therefore, he had a good understanding of the prospective concept.

Phase IV - Conceptual Change Strategies

Jack partially demonstrated the intelligibility of the concept during beginning of the second phase (see Table 2). He correctly recalled his initial understandings; he correctly concluded the relationships between the tension and weight vectors, and provided all correct answers on the new-knowledge activity. However, when the researcher began to discuss the topic within a different context, Jack demonstrated less confidence in his answers, "… (frustrated)…..when it's constant speed going down the weight stays the same across the whole range and tension stays the same; it doesn't go up or down. Right…I think that's right?" He was correct but began to experience doubt in his answers. Jack also correctly responded when the researcher changed the context of the conversation, asking him to consider a 170-pound person sitting in a rocket who was accelerating. Jack responded that:

> *Your weight is not going to change regardless (forcefully and convinced). You're going to weight the same no matter what, but momentarily, your normal force will change because I guess, you're overcoming.*

Jack indirectly demonstrated plausibility and fruitfulness when asked to provide an example of this concept. He spoke of beams and trusses in a structure in which an engineer might need to calculate “load” requirements that are actually necessary forces; he also cited an example of a concrete parking deck that utilized steel tension cables to secure the structure.

Jack utilized awareness at the very end of the second phase (see Table 3). When the researcher asked him to discuss the difficulty of understanding the topic, Jack stated that, “I guess once I’ve seen it on paper…until I’ve seen it written down, it’s easier.” Jack referred to his visual ability to learn a concept better when he sees it written rather than when it is abstract. Jack also utilized evaluation when asked to discuss the discrepant event outcome. He stated that:

> *….I don’t understand when it’s constant it stays the same which makes perfect sense…it just seems like it would be higher….I mean when you put weight on something obviously it creates tension but and I guess that makes sense once you think about it.*

Though the new concept was intelligible, plausible and fruitful, Jack still appeared not to have undergone conceptual change. His pre- and posttest answer to Question #18 were the same – he believed that the upward tension exceeded the weight force under constant speed.

Jack became exasperated when he was unable to account for the difference between his observations and his prediction. There were no instances of regulation or reflection.

Jack complete only regular level math courses; he had no physics or physical science courses. He assessed his struggle at 3 out of 10 (see Table 5). Jack stated that once the problem and concept is written down, enabling him to visualize it, the concept becomes easier, “I’ve been doing my homework, once I’ve seen it, I guess I new it had to be less when something is accelerating downward.”

When asked to complete the posttest, Jack selected the incorrect response to the question associated with the Elevator misconception. Thus, Jack did not successfully undergo conceptual change.

Summary

According to Posner, Strike, Hewson and Gertzog (1982), students who successfully undergo conceptual change utilize certain conceptual change characteristics to promote conceptual change. These characteristics as proposed by the Conceptual Change Model are (a) dissatisfaction with the existing conception; (b) ability to comprehend the new conception (intelligibility); (c) believing the potential conception to be true (plausible), and (d) finding the new conception usefulness (fruitful). Further, Wilson (1999) and Ertby and Newby (1996) lists awareness, evaluation, regulation and reflection as strategies required for undergoing conceptual change.

One of the items on the Force Concept Inventory (FCI) asked the students to identify the forces acting on a hockey puck that was moving along the x-axis suddenly experiencing a force directed perpendicular to the direction of travel. The researcher selected five students who believed, by their FCI responses, that the perpendicular force continued with the hockey puck through its trajectory.

The hope of the researcher was that each of the five students would undergo conceptual change, enabling them to understand that the perpendicular force did not continue with the hockey puck, thus adopting the “new concept.” The five students’ pseudonyms were Aaron, Benjamin, Caleb, Doug, and Edward. Of the students assigned to study this misconception, Aaron, Benjamin and Caleb experienced conceptual change; Doug and Edward failed to undergo conceptual change.

Aaron experienced dissatisfaction and found the scientifically accepted concept intelligible, and plausible. Though Benjamin did not demonstrate dissatisfaction, he accepted the concept as intelligible, plausible and fruitful. Doug demonstrated only that the concept was intelligible, plausible, and fruitful; Edward only demonstrated that the concept was intelligible (see Table 2).

Aaron and Benjamin experienced awareness, evaluation, regulation and reflection. Caleb demonstrated awareness, evaluation, regulation and reflection. Both Doug and Edward experienced awareness and regulation; only Doug demonstrated reflection (see Table 3).

A second misunderstanding among the students surfaced when an FCI question asked the students to consider an elevator moving upward in an elevator shaft at constant speed and to characterize the upward tension force. The results of this FCI question revealed that many students did not understand the relationship between the upward tension and the downward weight vectors under positive, negative and zero acceleration.

The researcher sought to promote conceptual change such that the students would embrace the “new concept” of understanding that a positive net force resulted in a positive acceleration and that a negative net force resulted in a negative acceleration.

The researcher selected a second group of five students who did not understand the concept of net force and its relationship to acceleration and assigned these students to study the Elevator Misconception. The pseudonyms for these students were Fred, Gary, Harold, Isaac and Jack. Of these students, only Gary experienced conceptual change.

With the Elevator Misconception, neither Gary nor Jack exhibited dissatisfaction; however, both did demonstrate that the concept was intelligible, plausible and fruitful. Isaac only exhibited that the concept was intelligible.

CHAPTER 5 – DISCUSSION AND IMPLICATIONS

Introduction

The purpose of this section was to discuss the findings of this research investigation. This has been accomplished in three sections: Discussion, Implications for Learning and Teaching and Implications for Future Research. The Discussion focuses on explaining the reasons that some students successfully underwent conceptual change and some who failed to undergo conceptual change. It considers the patterns associated with the Conceptual Change Model (CCM) proposed by Posner, Strike, Hewson and Gertzog (1982), and the conceptual change strategies outlined by Wilson (1999) and Ertby and Newby (1996)

The second section, Implications for Learning, discusses the impact of the research findings on student learning of physics concepts and their teaching. The final topic, Implications for Future Research, proposes the direction of additional research based on these research findings in this important area of science learning at the higher education level.

Discussion

This research investigation sought to focus on the conceptual change process of a group of students enrolled in a college-level Physics I course. All students began the course having one of the two misconceptions. One set of students incorrectly believed that a force exerted on a hockey puck by a hockey stick continued along the trajectory of the hockey puck, hence the term Hockey Puck Misconception. The second group of students began the investigation with an inconsistent understanding of the relationship between acceleration and tension, as in an elevator subjected to positive, negative or zero acceleration. The researcher referred to this portion of the investigation as the Elevator Misconception.

The following section explains the factors contributing to conceptual change in four sections: (a) Conceptual Change and Hierarchy of Understanding, (b) Conceptual Change and The Discrepant Event, (c) Conceptual Change and Cognitive Strategies, and (d) Conceptual Change and Perceived Difficulties of the Concept

Conceptual Change and Hierarchy of Understanding

According to constructivist theory, meaningful learning occurs when the learner relates new knowledge to relevant concepts within the learner's cognitive structures. Thus, an important factor in formulating broad and deep conceptual frameworks that will positively influence learning involves building upon knowledge already acquired by the learner – prior knowledge (Ausubel, 1968).

The construction of a sound conceptual foundation provides the foundation necessary for building new knowledge. The formation of a faulty foundation results in the formation of new knowledge that contradicts Newtonian physics. The belief in the existence of the "impetus" force is an example of a faulty conceptual foundation. DiSessa (1993) found that students commonly and incorrectly attributed the thrust of an object in free-fall flight to that of an "imparting force" or a "dying out" force.

The belief in the impetus force that acts on a hockey puck is a popular misconception among naïve thinkers – all five students assigned to study the Hockey Puck misconception believed in such a force (see Table 4). Students who relied on prior and faulty experiences rather than on established theory often constructed idiosyncratic and nonconforming understandings of the scientific concepts (DiSessa, 1993).

Three of the five students assigned to study the Hockey Puck Misconception also initially believed that equal masses suspended from an Atwood Pulley (see Figure 2) self-leveled. One student indicated that he based his beliefs on the operation of a two-pan balance in which equal masses on each of the two pans would level the balance. Additional discussions revealed that students fundamentally misunderstood the concept of acceleration. Without this understanding, students misunderstood net force, and regarded acceleration as being synonymous to velocity. Students were also unclear about the meaning of force and its implications. One student was unable to distinguish between force and acceleration, incorrectly believing that force created movement.

Students who studied the Elevator Misconception maintained misunderstandings similar to those students who studied the Hockey Puck Misconceptions. Discussions revealed that students were unclear about the relationship of opposing forces and accelerations and considered momentum as equal to force.

The ability to identify these forces correctly depended on students' existing understanding of four major topics (see Figure 5). First, students needed an understanding of the fundamental units of measurement and their corresponding units: length in meters, mass in grams and time in seconds. Second, students needed an understanding of kinematics, the study of motion, which involves velocity and acceleration; the units are meters per second (m/s), and meters per second squared (m/s^2), respectively. Third, students must understand the meaning of force and its composition: mass and acceleration. Fourth, students must understand the term "net force." The net force concept states that a net positive force results in a positive acceleration, a net negative force results in a negative acceleration (deceleration), and a net force of zero results in an acceleration of zero (constant velocity). Knowledge of kinematics coupled with Newton's Laws (F=ma, net force) helped to address the question of how an object might respond to a force, such as a hockey puck that has been struck by a hockey stick.

Aaron, Benjamin and Caleb successfully underwent conceptual change with the Hockey Puck misconception. Aaron completed both AP and Honors physics in high school, Caleb completed only regular physics, and Benjamin completed no physics in high school. Though Aaron believed in the impetus force, he demonstrated that he was knowledgeable about velocity and acceleration, mass and force, as well as the accompanying units at the beginning of the investigation. Though he was unclear about the conceptions of force was weak, he increased his understanding of force due to the discrepant event. Benjamin was less knowledgeable about velocity, acceleration, mass and force at the start of the investigation. Caleb maintained a relevant understanding of all kinematic quantities and of force.

Doug and Edward, both of whom did not experience conceptual change, completed regular level high school physics. Doug was unsure about the nature of force and acceleration and was not sure about the definition of mass. Likewise, Edward possessed an incorrect conception of mass, acceleration and force. Doug and Edward developed an unclear understanding of the fundamental units of measurement. Each also developed a less than adequate understanding of the critical kinematic quantities (see Table 7). These weak understandings contributed to their inability to undergo conceptual change because of the "broken path" within the hierarchy of understanding (see Figure 5)

Consequently, those having a strong sense of velocity, acceleration, and force more readily experienced conceptual change than did those who possessed weak conceptions of velocity, acceleration, and force. This suggests that a solid understanding of units, kinematics and force positively influence conceptual change.

The question on the FCI associated with the elevator misconception assessed the student's knowledge of forces under differing kinematic conditions. As was true with the former misconception, the student's ability to choose the correct response depended on their foundational knowledge in all of the same areas as with the previous misconception. However, the student experiencing conceptual change was required to have additional conceptual abilities. The student must have been able to identify the response of the force under constant velocity, under positive acceleration and under negative acceleration. The student also needed to be able to accomplish this qualitatively by understanding that tension is directly proportional to acceleration. The student may also have accomplished this by summing the forces in the y direction, algebraically solving for the tension. Students choosing the latter option must have been able to manipulate the equations algebraically, thus employing mathematical skills.

Gary was the only student to undergo conceptual change in the group that studied the Elevator Misconception. He completed AP physics and Honors algebra in high school. When considering the hierarchy of understanding of the knowledge necessary to undergo conceptual change, Gary was the only student studying the Elevator Misconception to have an understanding of all necessary conceptions (see Table 7). He firmly understood the system of units, the kinematics and had a firm grasp of the concepts related to Newton's Laws (F=ma and net force). Fred and Harold, who did not undergo conceptual change, completed all regular level high school courses. Fred grasped none of the concepts; Harold only understood acceleration. Isaac only completed physical science in high school. He only understood Newton's Laws. Jack completed regular level math courses, but did not take physical science or physics and did not grasp any of the concepts. Jack did not understand any of the concepts.

The ten students came into the class with a range of experience in physics; however, all carried misconceptions. Aaron, Benjamin, Caleb and Gary all shared a critical commonality in their understanding. Each maintained an understanding of the fundamental units of measurement, kinematics and force to facilitate conceptual change (see Table 7). According to the data, those who failed to undergo conceptual change lacked an understanding of those same concepts.

Consider the metaphor of a rooted tree undergoing growth to maturity. The tree grows from the roots upward. An interruption of the growth of the tree will in turn, interrupt the process of maturation. Likewise, a student enters the physics class with naïve understandings that are in need of conceptual change. Conceptual change can occur if the foundation has been prepared and if the process of understanding proceeds from the foundation "upward" toward comprehension. An interruption in the process results in failed conceptual change (see Figure 5). For example, understanding the fundamental units and kinematics will allow the student to proceed along the path (see Figure 5). If the student gets to "Force" and fails to understand "force," but attempts to continue along the path with this faulty understanding, one of two things will result. One, the student will not reach conceptual change or, two, the student will develop an additional misconception. Thus, students must build on a conceptual foundation in a hierarchical way, beginning with a foundational understanding and ending with the correct understanding of force to achieve conceptual change. The researcher refers to these understandings as the “hierarchy of understanding.” The data from this research investigation supports this assertion. A similar discussion applies to the Elevator Misconception and to Figure 6.

Conceptual Change and the Discrepant Event

Researchers utilize discrepant events to encourage students to confront naïve beliefs by allowing the student to design, carryout and verify the predictions thus promoting the construction of new understandings (McDermott, 1993; Hewson & Hewson, 1984). Further, many believe that the use of discrepant events invokes disequilibrium, which encourages student reflection of their conception as they attempt to resolve the conflict (Piaget, 1972). In this investigation, the researcher utilized the discrepant event to facilitate the students’ building of understanding, thus promoting conceptual change from both misconceptions to scientifically consistent ones. However, the use of the discrepant event in this investigation did not result in successful conceptual change in each case as the literature suggests.

Some scholars have concluded that the use of discrepant events is ineffective, believing only those bright and successful students will react enthusiastically to conceptual conflict, but that unsuccessful students will ignore these conflicts altogether (Dreyful, Jungwirth, & Eliovitch, 1990). Other scholars believe that students will avoid conceptual change by ignoring the conceptual conflict completely (Niaz, 1995), while other students will avoid a resolution, and that other students will yet cling to alternate conceptions (Trumper, 1997).

Each student participant who failed to undergo conceptual change appeared to understand the concept demonstrated by the discrepant event, but completely ignored the results. Consequently, students were unable to connect the results of the discrepant event to the misconception, thus holding on to the misconception or embracing an alternate conception. For example, the discrepant event helped Doug, Edward and Harold to understand the relationship between acceleration and force but, they maintained the misconception. Carey (1985) refers to this phenomenon as “weak restructuring,” which is the rearrangement of relationships between existing concepts. Through weak restructuring, concepts are not changed, but the applicability is extended or restricted (Carey, 1985). Doug, Edward and Harold only comprehended the concept within one context; when the context changed, they demonstrated non-comprehension. Doug, Edward and Harold did not undergo conceptual change.

Conceptual Change and Cognitive Strategies

Though the CCM suggests that undergoing conceptual change requires dissatisfaction with the current conception, and that the proposed conception must be intelligible, plausible and fruitful, the results of this investigation did not agree (see Table 2).

The Elevator Misconception

Aaron, who did undergo conceptual change, did experience dissatisfaction, intelligibility and plausibility as the CCM would suggest. However, he did not find the new conception to be fruitful as applied to other contexts, likely attributable to his exceptional preparation which enabled him to easily re-align his conception without regarding the proposed conception as valuable. Benjamin and Caleb did not demonstrate dissatisfaction with their existing conception. Benjamin, however, did, demonstrate intelligibility, plausibility and fruitfulness with the new conception. Caleb only demonstrated intelligibility and plausibility with the new conception. Neither Doug nor Edward, who did not experience conceptual change, demonstrated dissatisfaction, also as the CCM would suggest. However, Doug considered the new conception as intelligible, plausible and fruitful; Edward only demonstrated intelligibility.

When contrasting the use of the CCM characteristics among the participants, the most significant difference occurred in the use of dissatisfaction. Only Aaron appeared dissatisfied with his current conception. No differences attributed to learning existed in the use of the remaining CCM characteristics between those who underwent conceptual change and those who did not.

The researcher did discover a more consistent pattern in the use of conceptual change strategies among participants (see Table 3). Of the students that were successful in conceptual change, Aaron and Benjamin exhibited awareness, evaluation, regulation and reflection in the process of conceptual change. Caleb exhibited awareness, evaluation and regulation. This pattern contrasts with those strategies demonstrated by students who were not successful in their conceptual change. Doug demonstrated awareness, evaluation and reflection. Edward exhibited only awareness and evaluation. Neither Doug nor Edward exhibited regulation.

This pattern, somewhat consistent with Wilson (1999) and Ertmer and Newby (1996), suggests that those who undergo conceptual change must be aware of the conflict between their existing conception and those of the proposed understanding. The student must evaluate his/her thinking capacities and limitations during the conceptual conflict and assess the effectiveness of his/her thinking. Further, students who undergo conceptual change must also experience regulation, which enables them to modify their thinking, thus accepting the new conception and jettisoning the old one. In addition, conceptual reflection refers to evaluating the sensibility of the new conception, judging whether to accept the new conception, and assessing credibility of the examples used during the conceptual conflict.

An unexpected phenomenon, however, surfaced in the data that did not support Wilson (1999) and Ertmer and Newby's (1996) findings. This unexpected phenomenon was associated with the strategy of reflection. Recall that experiencing awareness, evaluation, and regulation, and reflection suggests conceptual change (Wilson ,1999; Ertmer &Newby, 1996). Caleb, who underwent conceptual change, experienced awareness, evaluation and regulation, but did not experience reflection. Doug, who did not experience conceptual change, experienced all but regulation. Why then, was Caleb able to undergo conceptual change without experiencing reflection? It is the belief of the researcher that the answer lies in the hierarchy of knowledge possessed by Caleb (see Table 7).

Caleb developed a complete understanding of the four components of the hierarchy of knowledge: kinematics and of Newton's Laws. He understood the fundamental units, he developed an understanding of kinematics, and he understood that zero acceleration resulted in zero force and that a positive acceleration resulted in a positive force. He satisfied the requirements of constructivist theory by formulating new understandings atop prior knowledge enabling him to undergo conceptual change, without the use of conceptual reflection. Thus, Caleb accommodated the new conception, which accounted for the change in fundamental belief about how the world works (Dykstra, Boyle, & Monarch, 1992), thus undergoing conceptual change.

Doug began the investigation with misunderstandings of the role of the impetus force, a misunderstanding of the distinction between acceleration and speed, a misunderstanding of inertia, force and of acceleration. Again, considering the hierarchy of knowledge (see Figure 5), Doug's initial foundation of understanding was considerably weaker than that of Caleb. He lacked a clear understanding of the fundamental quantities, kinematics and Newton's Laws, which contributed to his failure to undergo conceptual change. Doug effectively underwent conceptual assimilation in which he recognized that an event fit the existing conception while selectively ignoring the discrepancies of the discrepant event (Dykstra, Boyle, & Monarch, 1992). Consequently, Doug experienced weak restructuring, which involved the simple rearrangement of the concepts (Carey, 1985). When the context of the problem changed, he reverted to his original conception.

The conclusion drawn about the pattern of the CCM for the elevator misconception is similar to that drawn about the hockey puck misconception (see Table 2). There were no discernable patterns in the CCM when comparing those who experienced conceptual change to those who did not experience conceptual change associated with the elevator misconception. None of the students seemed dissatisfied with their prior understanding. Gary was the only student who experienced conceptual change that demonstrated each of the remaining three patterns: intelligibility, plausibility, and fruitfulness. Jack, who did not experience conceptual change, also demonstrated intelligibility, plausibility, and fruitfulness. Isaac demonstrated only intelligibility. Fred and Harold exhibited none of the CCM characteristics.

The Elevator Misconception

Gary exhibited all four conceptual change strategies of awareness, evaluation, regulation and reflection in achieving conceptual change. Of the remaining research participants that failed to undergo conceptual change, none demonstrated use of all of the conceptual change strategies. Fred demonstrated awareness, evaluation and reflection, Harold and Isaac demonstrated evaluation and reflection; Jack utilized only awareness and evaluation.

As was found with the Hockey Puck misconception, understanding the concepts found in the hierarchy of understanding is crucial to achieving conceptual change. Gary was the only student who studied the Elevator Misconception and successfully underwent conceptual change, he experienced all four of the Wilson (1999) and Ertmer and Newby's (1996) characteristics. Further, he mastered each of the concepts associated with the hierarchy of understanding, which has become a credible predictor of conceptual change. Again, these data support the Hierarchy of Understanding idea (see Figure 5 and Figure 6).

Conceptual Change and Perceived Difficulties of the Concept

Understanding the Hockey Puck scenario required knowledge of fundamental units, kinematics and force. Aaron, Benjamin and Caleb, who underwent conceptual change with the Hockey Puck misconception, considered the level of difficulty of understanding the concept to be moderately easy (see Table 5). Doug and Edward, who did not undergo conceptual change, considered this concept as being more difficult. Thus, those who underwent conceptual change with the Hockey Puck misconception perceived this conception to be "easier" than those who did not undergo conceptual change because of the hierarchy of understanding that they had developed.

Gary, who underwent conceptual change with the Elevator Misconception, felt that this conception was moderately easy (see Table 5). Harold and Isaac considered understanding the concept as more difficult than did Gary. Jack, who did not undergo conceptual change, considered the concept at the same level of difficulty as did Gary. Fred considered it very difficult.

The overall pattern that emerged across both misconceptions is that students who underwent conceptual change perceived the concept as being easier than those who did not undergo conceptual change (see Table 5).

Implications for Learning

During the process of promoting conceptual change, the researcher made several discoveries. One, prior exposure to physics concepts positively influenced the likelihood of conceptual change. Two, CCM did not rigorously predict or necessarily promote conceptual change as the research literature suggested. Three, students who underwent conceptual change considered the concept as easy; those who did not undergo conceptual change considered the concepts as difficult. Finally, familiarity with the concepts associated with the hierarchy of understanding increased the likelihood of conceptual change.

This section will present suggestions toward improving physics learning such that students entering the beginning college-level physics course will complete the course with scientifically consistent conceptions. The researcher will accomplish this in two sections. They are “Constructivists Implications in Learning Physics” and “Cognitive Strategies and Learning Physics.”

Constructivists Implications in Learning and Teaching

Constructivist principles have several implications that are appropriate for use within the science classroom. First, if students must utilize their current and prior understandings in new contexts to build new knowledge, then teachers must engage students in learning and must start the instruction “where the students is.” Teachers can ensure that learning experiences incorporate problems that are relevant to students, not those that are important to teachers.

Second, constructivist theory states that learning is based on prior knowledge; teachers must acknowledge those prior experiences and provide learning environments that exploit inconsistencies between learners' current understandings and the new experiences. Within the constructivist paradigm students develop, test and revise their ideas about the phenomena under consideration through collaborative inquiry with their peers (Smith et al., 2000). These cognitive processes require a willingness and ability of the student to recognize, evaluate and reconstruct existing beliefs. Consequently, students selectively attend to information, activate prior conceptual knowledge, monitor comprehension and assess the status of the new information relative to prior conceptions while cognitively engaging in academic tasks (Hennessey, 2003). The role of the facilitator/instructor is to promote learning by utilizing constructivist theory to establish a target concept, posing an inquiry question; providing an opportunity for the student to confront current understandings in light of the new experience, and finally engaging in a discussion to promote learning. Further, the facilitator needs to provide various experiences to advance the learner to different levels of understanding (SEDL, 2001).

Third, the constructing of new knowledge requires time. Ample time facilitates student reflection about new experiences, the way those experiences compare to current understandings, and how a different understandings might provide students with an improved view of the world (SEDL, 2001). The range of time spent on the discrepant event ranged from a low of twenty-seven minutes (Gary) to a maximum of one hour (Caleb).

Naive learners enter the physics classroom with an existing knowledge base derived from their everyday experiences (Hestenes & Halloun, 1985a). Currently, class textbooks do not address misconceptions, and most instructors completely ignore any discussion regarding student misconceptions. Instructors must realize that naïve understandings present obstacles to learning and be prepared to generate discussions needed to confront misconceptions.

Classroom teachers can promote learning by exposing naïve concepts and confronting them directly (Pintrich et al., 1993). These confrontations must be more than simply teaching the concepts correctly. Rather, strategies must focus on experience-based instruction within the context of the classroom and must provide a motivational incentive to alter these conceptions (Bruning, Schraw, & Ronning, 1999).

Encouraging group discussion, getting them to understand that their belief contrasts with that of the scientific community may be effective. The instructor can then provide an activity that will cause students to question their beliefs. Finally, the instructor can provide an activity within a different context, allowing the student to utilize the new knowledge within the new context.

Cognitive Strategies and Learning Physics

Students sparingly utilized four cognitive strategies to accomplish conceptual change: awareness, evaluation, regulation and reflection. These strategies within the constructivists context allow students to develop, test and revise their ideas (Smith et al., 2000) and require a willingness and ability to recognize, evaluate and reconstruct existing beliefs on the part of the learner. As such, students must selectively attend to information, activate prior conceptual knowledge, monitor comprehension and assess the status of the new information relative to prior conceptions, while cognitively engaging in academic tasks (Hennessey, 2003). Building knowledge demands a large magnitude of declarative and procedural knowledge. The complexity of the knowledge relationships, as well as the amount of available information makes knowledge building an especially daunting task. One of the objectives in knowledge construction is for the students to become self-directed in their construction, having an organized foundational array. Through this process, they can respond to questions of what, how, why and when. One way of accomplishing this is to for students to develop their information-seeking skills. Through the process of searching, assessing and evaluating information, students sharpen their construction skills, especially in the context of a long-term assignment (Bruning, Schraw, & Ronning, 1999).

Another strategy to promote knowledge construction is using discourse. In this way, students learn by discussing and grappling with concepts over time. It is through the process of "wrestling" with the problems that knowledge construction occurs. Students with immature notions often can work through and build those notions by utilizing discourse with more mature learners. This strategy is similar to utilizing the modeling strategy in problem-solving in which an observer labors through a problem with an expert (Bruning, Schraw, & Ronning, 1999).

Preparing for a discussion fosters knowledge construction and understanding. Discussion is important in that it helps students build an array in which to organize new information. For example, before discussions, teachers can facilitate the development of the learning agendas for the students; during the discussions, teachers can help students to clarify their understandings; after the discussions, teachers can help students to reflect on their learning experience. In this way, students simply "plug" in the holes in the scaffold with the new information. The benefit of the scaffold is that the correct relationship between the new information and prior information exists (Bruning, Schraw, & Ronning, 1999).

The data from this investigation suggest that conceptions perceived by students as intelligible and plausible would promote conceptual change. Intelligibility refers to deep comprehension of the conception, for it is this deep understanding that allows the students to formulate strong conceptual frameworks (Meyers, 1993). Further, the correctness of existing conceptions on which to build new knowledge coupled to incoming knowledge creates the conditions necessary for the construction of new knowledge that is vital for the occurrence of deep learning.

Plausibility suggests that the student must perceive the conception as credible. Again, this may be accomplished by allowing the student to personally discover the knowledge, thus making the connection between the concept and reality. This was accomplished with the Elevator Misconception by simulating the forces acting on an elevator with the Atwood Pulley (see Figure 3) and spring gauges. During the positive acceleration the student could visually experience the increased tension as demonstrated by the force on the spring gage.

The data also suggest that students' metacognitive awareness, evaluation and regulation promote conceptual change. According to Wilson (1999), metacognitive awareness is the individual's awareness of his/her progress in the learning process, awareness about his/her knowledge concerning content knowledge, and awareness about personal learning strategies. Metacognitive evaluation is the judgment made regarding one's thinking capacities and limitations as these are employed in a particular situation. Further, it is the assessment of the effectiveness of their thinking or strategy of choice. Metacognitive regulation occurs when individuals modify their thinking. Metacognitive regulation draws upon knowledge and makes effective use of available cognitive resources (Ferrari & Elik, 2003). Therefore, students who monitor their learning metacognitively are more likely to encounter conceptual change than those who are not.

Becoming metacognitive includes the ability to ask and answer a series of questions. One, the student must be aware of what he knows, what he needs to know and where to find it. Two, the student must assess his understanding of what was just heard, read or calculated. Three, the student must be aware of time, and his rate of learning and know if it is appropriate. Finally, the student must be aware of the existence of possible errors and how to spot them. Finally, the student must determine if the plan must be revised (Huitt, 1997).

Summary

Hestenes and Halloun (1985a) refer to students who enter beginning physics courses with prior knowledge derived from daily experiences as naïve thinkers. Often, their understandings are inconsistent with those of the scientific community. Theorists characterize the naïve thinkers as ones who maintain undifferentiated concepts of velocity and acceleration, lack a force concept, and have developed a fragmented concept about force and motion. These undifferentiated concepts lead to misconceptions. Many of the misconceptions maintained by non-Newtonian thinkers interfere with future learning, exacerbate the formulation of new and scientifically acceptable conceptions (Klammer, 1998) and thrive as useful and intuitive beliefs (Dykstra, Boyle, & Monarch, 1992).

Students desiring to become technical professionals and scientifically literate must develop a strong conceptual understanding of various areas within science. The understanding of classical mechanics and Newton's Laws provide the constructivist foundation upon which all other branches of science and engineering rest. Students, who have developed poor conceptions, must undergo conceptual change.

Students can achieve conceptual change in several ways. First, using discourse in allowing the student with the weak conception to articulate his understanding promotes conceptual change. Second, ensuring student plausibility and intelligibility helps the student to understand the conception and to view it as credible promotes conceptual change. Finally, focusing on student metacognition also promotes conceptual change by encouraging the student to self-monitor the process of learning.

If students in the United States are to achieve scientific literacy, university professors will need to embrace the idea that allowing students to construct their own knowledge is more beneficial than exposing them to the traditional methods of instruction. Hence, accepting scientific inquiry, which lends itself well to knowledge construction (constructivism), is a first step in the process. Further, achieving scientific literacy among university students requires that the instructor assume a role of facilitator in leading the student to the correct concept, rather than attempting to indoctrinate the student. Finally, university physics professors, who are not normally concerned with prior knowledge, must consider the conceptions brought into the classroom by students and the impact that these conceptions have on future learning.

Limitations of the Study

This research project sought to investigate the strategies used by students who underwent conceptual change. The project methodology involved two limitations. They were researcher's bias and interpretive bias.

Researcher's bias refers to developing conclusions prematurely – before completing the collection and analysis of the data. As the researcher investigator, my bias in this investigation is likely related to constructivism. Seventeen years of teaching college level physics has developed some amount of skepticism of constructivist theory within me. Though I fully accepted the idea of building on prior knowledge, it is difficult for me to surrendering the tasks of my perceptions about teaching. This was very difficult for me because I had to accept that learning was the responsibility of students and my role of "facilitator" was what was needed in this study. Subsequently, I found it difficult not to lecture but to facilitate the learning process throughout this investigation.

Interpretive bias refers to the subjectivity involved with analyzing qualitative data. This subjective nature and my desire for objectivity caused me to struggle with properly establishing the lines of demarcation for each of the conceptual change characteristics and strategies.

Implications for Future Research

The conclusions of this research project provide opportunities for additional research. Though the research literature suggests that struggling through science is gender-specific as well as culture-specific, additional research is needed to assess the conceptual change process within the domain of physics based on gender and culture. That is, how do the conceptual change processes among those who successfully undergo conceptual change compare and contrast to those who do not undergo conceptual change attributed to cultural and gender-related experiences and knowledge? Subsequent researchers may establish the following as research questions:

(1) What are the strategies used by students who are successful in undergoing conceptual change when studying Newton's Laws in a first semester college-level physics course on the basis of cultural experiences, experience and knowledge?

(2) What are the strategies used by students who are successful in undergoing conceptual change when studying Newton's Laws in a first semester college-level physics course on the basis of gender experiences and knowledge?

(3) What are the different levels of knowledge in the study of Newton’s Laws that would suggest conceptual change related to knowledge and experiences?

Answers to these questions may provide insight into further promoting conceptual change in the study of physics concepts in higher education.

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Appendix A

Force Concepts Inventory

Appendix A

Force Concepts Inventory Revision 01

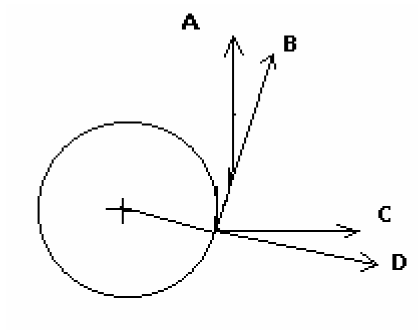
(Reference David Hestenes, Malcolm Wells, Gregg Swackhamer)

1. Two metal balls are the same size, but one weighs twice as much as the other. The balls are dropped from the top of a two-story building at the same instant of time. The time it takes the balls to reach the ground below will be:
   f. about half as long for the heavier ball
   g. about half as long for the lighter ball
   h. considerably less for the heavier ball, but not necessarily half as long
   i. considerably less for the lighter ball, but not necessarily half as long.
   j. About the same time for both balls.

2. Imagine a head-on collision between a large truck and a small compact car. During the collision
   a. the truck exerts a greater amount of force on the car then the car exerts on the truck
   b. the car exerts a greater amount of force on the truck then the car truck exerts on the car
   c. the truck exerts a force on the car but the car doesn't exert a force on the truck
   d. the truck exerts the same amount of force on the car as the car exerts on the truck

3. Two steel balls, one of which weighs twice as much as the other, roll of a horizontal table with the same speeds. In this situation.
   a. Both balls impact the floor at approximately the same horizontal distance from the base of the table.
   b. The heavier ball impacts the floor at about half the horizontal distance from the base of the table than does the lighter.
   c. The lighter ball impacts the floor at about half the horizontal distance from the base of the table than does the heavier.
   d. The heavier ball hits considerable closer to the base of the table than the lighter, but not necessarily half the horizontal distance.
   e. The lighter ball hits considerably closer to the base of the table than the heavier, but not necessarily half the horizontal distance.

4. A heavy ball is attached to a string and swung in a circular path in a horizontal plane. At the point indicated in the diagram, the string suddenly breaks at the ball. If these events were observed from directly above, indicate the path of the ball after the string breaks:

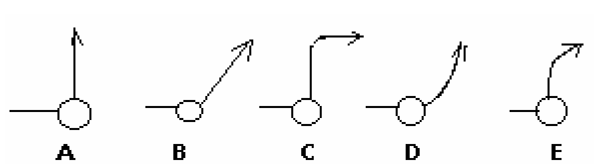


5. A boy throws a steel ball straight up. Disregarding any effects of air resistance, the force(s) acting on the ball until it returns to the ground is (are):
   a. its weight vertically downward along with a steadily decreasing upward force
   b. a steadily decreasing upward force from the moment it leaves the hand until it reaches its highest point beyond which there is a steadily increasing downward force of gravity as the object gets closer tot he earth
   c. a constant downward force of gravity along with an upward force that steadily decreases until the ball reaches its highest point, after which there is only the constant downward force of gravity
   d. a constant downward force of gravity only

Use the statement and diagram below to answer the next four questions: The diagram depicts a hockey puck sliding, with a constant velocity, from point "A" to point "B" along a frictionless horizontal surface. When the puck reaches point "B" it receives an

instantaneous horizontal "kick" in the direction of the heavy print arrow:

6. Along which of the paths below will the hockey puck move after receiving the "kick"

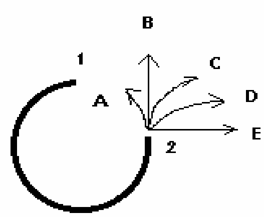


7. The speed of the puck just after it receives the kick?
   a. equal to the speed "v_o" it had before it received the kick
   b. Equal to the speed " v_f " it acquires from the "kick" and independent of the speed " v_o."
   c. Equal to the arithmetic sum of speed of " v_o " and " v_f "
   d. Smaller than either of speeds " v_o " or " v_f "
   e. Greater than either of speeds " v_o " or " v_f " but smaller than the arithmetic sum of these two speeds.

8. Along the frictionless path you have chosen, how does the speed of the puck vary after receiving the kick.
   a. no change
   b. continuously increasing
   c. continuously decreasing
   d. increasing for a while, and decreasing thereafter
   e. Constant for a while and decreasing thereafter.

9. The main forces acting after the kick on the puck along the path you have chosen are:
   f. the downward force due to gravity and the effect of air pressure
   g. The downward force of gravity and the horizontal force of momentum in the direction of motion.
   h. The downward force of gravity, the upward force exerted by the table, and horizontal force acting on the puck in the direction of motion.
   i. The downward force of gravity and an upward force exerted on the puck by the table
   j. Gravity does not exert a force on the puck; it falls because of the intrinsic tendency of the object to fall to its natural place.

10. The accompanying diagram depicts a semicircular channel that has been securely attached, in a horizontal plane, to a tabletop. A ball enters the channel at '1" and



exists at "2". Which of the path representations wold most nearly correspond to the path of the ball as it exists the channel at "2" and rolls across the tabletop.

Two students, student "A" who has a mass of 95 kg and student "B" who has a mass of 77 kg sits in identical office chairs facing each other. Student "A: places his bare feet on student "B's " knees. Student "A" then suddenly pushes outward with his feet causing both chairs to move.

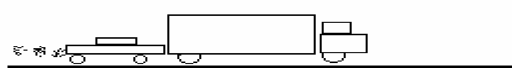
11. In this situation

a. neither student exerts a force on the other
b. student "A" exerts a force on "B", but "B" doesn't exert any force on "A"
c. each student exerts a force on the other but "B" exerts the larger force
d. each student exerts a force on the other but "A" exerts the larger force
e. Each exerts the same force on the other.

12. A book is at rest on a tabletop. Which of the following force(s) is (are) acting on the book?
    1. a downward force due to gravity
    2. the upward force by the table
    3. a net downward force due to air pressure
    4. a net upward force due to air pressure

a. 1 only
b. 1 and 2
c. 1,2 and 3
d. 1,2 and 4
e. None of these since the book is at rest there are no forces acting on it.

Refer to the following statement and diagram while answering the next two questions. A large truck breaks down out on the road and receives a push back into town by a small



compact car.

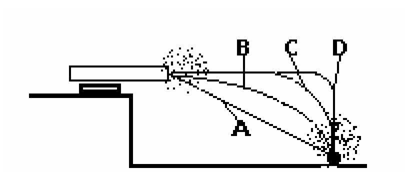
13. While the car, still pushing the truck, is speeding up to get up to cruising speed:
    a. The amount of force of the car pushing against the truck is equal to that of the truck pushing back against the car.
    b. The amount of force of the car pushing against the truck is less than that of the truck pushing back against the car
    c. The amount of force of the car pushing against the truck is greater than that of the truck pushing against the car
    d. The car's engine is running so it applies a force as it pushes against the truck but the trucks engine is not running so it can't push back against the car, the truck is pushed forward simply because it is in the way of the car
    e. Neither the car nor the truck exert any force n the other, the truck is pushed forward simply because it is in the way of the car.

14. After the person in the car, while pushing the truck, reaches the cruising speed at which he/she wishes to continue to travel at a constant speed:
    a. the amount of force of the car pushing against the truck is equal to that of the truck pushing back against the car
    b. The amount of force of the car pushing against the truck is less than that of the truck pushing back against the cr.
    c. The amount of force of the car pushing against the truck is greater than that of the truck pushing against the car.

d. The car's engine is running so it applies a force as it pushes against the truck but the forward simply because it is in the way of the car
e. Neither the car nor the truck exert any force on the other, the truck is pushed forward simply because it is in the way of the car.

15. When a rubber ball dropped from rest bounces off the floor, its direction of motion is reversed because:
a. energy of the ball is conserved
b. momentum of the ball is conserved
c. the floor exerts a force on the ball that stops its fall and then drives it upward
d. The floor is in the way and the ball has to keep moving.
e. None of the above

16. Which of the paths in the diagram to the right best represents the path of the



cannon ball?

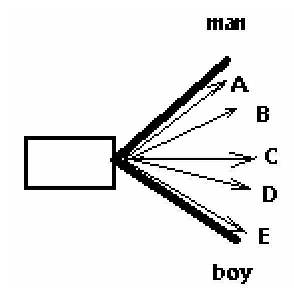
17. A stone falling from the roof of a single story building to the surface of the earth
a. reaches its maximum speed quite soon after release and then falls at a constant speed thereafter
b. Speeds up as it falls, primarily because the closer the stone gets to the earth, the stronger the gravitational attraction.
c. Speeds up because of the constant gravitational force acting on it.
d. Falls because of the intrinsic tendency of all objects to fall toward the earth
e. Falls because of a combination of the force of gravity and the air pressure pushing it downward.

When responding to the following question, assume that any frictional forces due to air resistance are so small that they can be ignored.

18. An elevator, as illustrated, is being lifted up an elevator shaft by a steel cable. When the elevator is moving up the shaft at constant velocity
f. the upward force on the elevator by the cable is greater than the downward force of gravity
g. The amount of upward force on the elevator by the cables equals to that of the downward force of gravity.
h. The upward force on the elevator by the cable is less than the downward force of gravity.

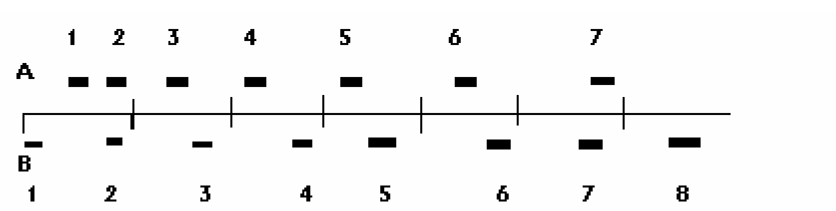
i. It goes up because the cable is being shortened, not because of the force being exerted on the elevator by the cable
j. The upward force on the elevator by the cable is greater than the downward force due to the combined effects of air pressure and the force of gravity

19. Two people, a large man and a boy, are pulling as hard as they can on two ropes



attached to a crater as illustrated in the diagram. Which of the indicated paths (A-E) would most likely correspond to the path of the crate as they pull it along?

The positions of two blocks at successive 0.20-second time intervals are represented by the numbered squares in the diagram. The blocks are moving toward the right.



20. Do the blocks every have the same speed
a. no
b. yes, at instant 2
c. yes, as instant 5
d. yes, at instant 2 and 5
e. yes, at some time during interval 3 and 4

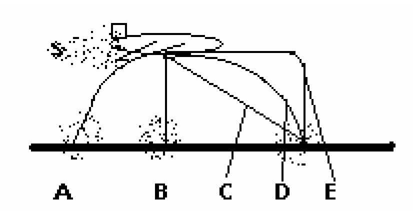
21. The acceleration of the blocks are related as follows:
a. acceleration of "a" > acceleration of "b"
b. acceleration of "a" = acceleration of "b" >0
c. acceleration of "b" > acceleration of "a"
d. acceleration of "a" = acceleration of "b"=0
e. not enough information to answer

22. A golf ball is driven down a fairway through a normal trajectory. Which of the forces are acting on the golf ball during its entire flight:

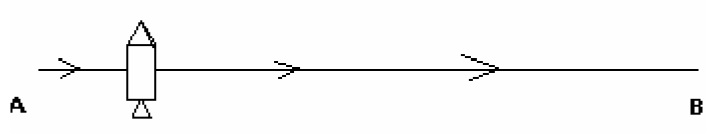
1. the force of gravity
2. the force of the "hit"
3. the force of air resistance

a. 1 only
b. 1 and 2
c. 1,2,and 3
d. 1 and 3
e. 2 and 3

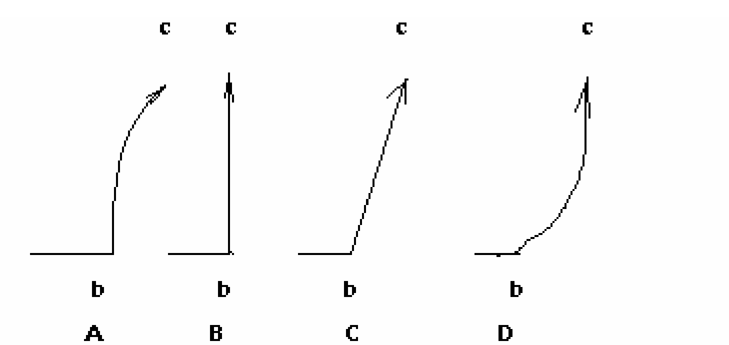
23. A bowling ball accidentally falls out of a cargo bay of an airliner as it flies horizontal. Which path would of the ball most closely follow after falling from the plane?



When answering the next four questions, refer to the following statement and diagram. A rocket, drifting sideways in outer space from position "A" to position "B" is subject to no outside forces. At "B", the rocket's engine starts to produce a constant thrust at right angles to line AB. The engine turns off again as the rocket reaches some point "C".



24. Which path below best represents the path of the rocket between "B" and "C"?



25. As the rocket moves from "b" to "c" its speed is:

   a. constant
   b. continuously increasing
   c. continuously decreasing
   d. increasing for a while and constant thereafter
   e. constant for a while and decreasing thereafter.

Appendix B

Time Sequence for the Investigation

Appendix B

Time Sequence for the Investigation

Chapter 1 – Mathematical Concepts Chapter 2 – One Dimensional Kinematics Chapter 3 – Two Dimensional Kinematics	• Administer FCI • Administer Student Demographic Survey • Review FCI; Select top two misconceptions for the study • Randomly select research participants • Phase I – "Acknowledging Their Understandings" • Phase II – "Collecting Evidence"
Chapter 4 – Newton's Laws	No Research Activity
	• Phase III – "New Knowledge Activity" • Phase IV – "Conceptual Change Strategies"
Chapter 5 – Circular Motion	Continue collecting data
Chapter 6 – Work and Energy	Continue collecting data
Chapter 7 – Impulse and Momentum	Continue collecting data
Chapter 8 – Rotational Kinematics	Transcribe data
Chapter 9 – Rotational Dynamics	Transcribe data
Chapter 10 – Simple Harmonic Motion	Transcribe data
Chapter 16 – Waves and Sound	Transcribe data
Chapter 17 – Linear Superposition	Analyze data
Chapter 11 – Fluids	Analyze data
Chapter 12 – Temperature and Heat	Analyze data
Chapter 13 – Heat Transfer	Analyze data

Appendix C

Student Demographic

Appendix C

Student Demographic (Rev 05)

Personal Id #	______________	Today's Date	______________	
Age:	______________	Gender:	______________	
Ethnicity:	African	African Am.	Asian	
	Asian American	European American	Hispanic/Latino	
	Pacific Islander	Native Am.	Middle Eastern	
	Other _______			
Academic Status:	Freshman	Sophomore Junior	Senior	
Academic Major:	_____________			
High School GPA	______________	College GPA	______________	
Pre-Test Score	______________	Post Test Score	______________	

Previous Courses Taken (Please Circle all that apply)

	Physical Science	Regular Level	AP	Honors
	Physics	Regular Level	AP	Honors
	Algebra I	Regular Level	AP	Honors
	Algebra II	Regular Level	AP	Honors
	Geometry	Regular Level	AP	Honors
	Trigonometry	Regular Level	AP	Honors
	Calculus	Regular Level	AP	Honors

Appendix D

Lesson Plan

Teaching for Conceptual Change

Appendix D

Lesson Plan

Teaching for Conceptual Change

Phase I – Acknowledging their Understanding - The goal is to encourage the student to acknowledge their understanding for each of the misconceptions by making their notions explicit.

- Discuss the results of the FCI that are related to the misconception under review with each student.
- The discussion will focus on encouraging the student reveal personal ideas; provide support for these ideas to, and to articulate their understanding about the physical phenomenon.
- Students will be encouraged to respond orally to the FCI questions that are related to the misconception.

Phase II – Collecting Evidence - The goal is to present a discrepant event to the student that will motivate the student to confront his own conception in light of the outcome of the discrepant event.

- The researcher will design a problem (discrepant event) related to the misconception under study and present this problem to each student.
- The student will record his/her prediction on the discrepant event prediction (Brandsford, et al, 2000) (Appendix E).
- The student will observe the outcome, and record any measurements.
- Through the discussion that will follow, the student will hopefully begin to confront the prior conception against the new conception, thus regarding the new one as intelligible.
- Possible questions:
  - What is your current understanding of the concept
  - If your understanding has changed, why
  - Does the prior concept make sense? Why or why not
  - Does the new concept make sense? Why or why not

Phase III – Practicing - The objective is to provide opportunities for the student to utilize the new ideas in a different context.

- Each student will be provided an activity that is related to the concept under study and asked to solve a problem. The problem will be related to each of the two misconceptions.

Phase IV – Conceptual Change Strategies – The objective is to determine the strategies used by students who successfully underwent conceptual change.

- The researcher will infer as to the strategies used.

This Lesson Plan will be repeated for each of the misconceptions under study and for each student on an individual basis. Each session will be videotaped.

Appendix E

Discrepant Event Prediction

Appendix E

Discrepant Event Prediction

1. Please make a prediction as to the outcome of this event before the discussion with the researcher. Record your prediction below.

2. Please record the outcome of this event after the demonstration.

3. Is your prediction the same as the outcome observed from the experiment? Why or why not.

4. What accounts for the difference in your prediction and the outcome as observed from the experiment?

Appendix F

Prompters - Determining Conceptual Change Strategies

Appendix F

Prompters - Determining Conceptual Change Strategies

Awareness

Describe the concept under question.

State your ideas regarding the concept. What is your understanding?

Why have you adopted this idea (“the what as well as the why)?

Are your ideas consistent with scientific theory?

Do you realize the limitation of your ideas as the possibility they might need to be changed?

Regulation

What is the best way to proceed with solving this problem?

Are there different ways to solve this problem?

What can you do next?

What is your current understanding of the concept?

Evaluation

Is the answer that you’re getting correct

Are you able to complete this exercise

Is what you’re doing working

Can you apply intelligible and plausible to your own ideas?

Reflection

Do my answers make sense?

How did I get to this point?

Can you try to explain your ideas using physical models?

Ref: (Wilson, J. 1999); (Beeth & Hewson, 1997); (Ertmer, P. A., & Newby, T. J. (1996).

Appendix G

New Conception in a New Context

Appendix G

New Conception in a New Context

1. Please determine the outcome of the problem provided. Record your prediction below.

   ____

   ____

   ____

2. Discuss your reason for your response on #1.

   ____

   ____

   ____

Appendix H

Prompters - Perceived Level of Difficulty of the Concept to Conceptual Change

Appendix H

Prompters - Perceived Level of Difficulty of the Concept to Conceptual Change

1. Nature of the concept
   a. Did you find this concept difficult to comprehend?
   b. If so, what did you find difficult about the concept?
   c. Describe the use of this concept in real life.

2. Initial Understanding of the Concept
   a. What was your initial understanding of the concept?
   b. Was your initial understanding correct or incorrect, and why?

3. Current understanding of the concept
   a. What is your current understanding of the concept?
   b. How is this concept used in real-life applications?

4. The Process of conceptual change
   a. How difficult was it for you to come to the understanding that you now have?
   b. How effective was the exercise in helping to achieve the understanding of the concept that you now have?
   c. What helped you to arrive at the understanding that you now have?

Appendix I

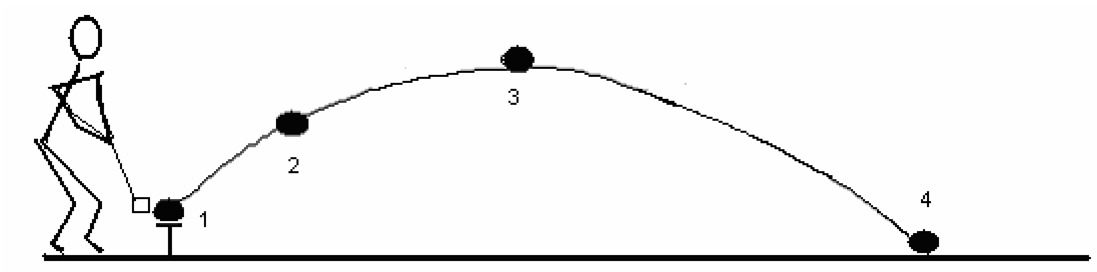
Using New Knowledge – The Hockey Puck Misconception

Appendix I

Using New Knowledge – The Hockey Puck Misconception

Name: __________________________ ID#: _________________

Solve the following problem: Consider a golf ball sitting on the golf tee. The golfer strikes the ball with the club as shown in the diagram below. Identify all forces on the ball at the four points in the diagram.



1. Being struck by the golf club ____

2. After being struck by the golf club_____________________________________

3. Reaching maximum height____

4. After coming to rest on the ground_____________________________________

Appendix J

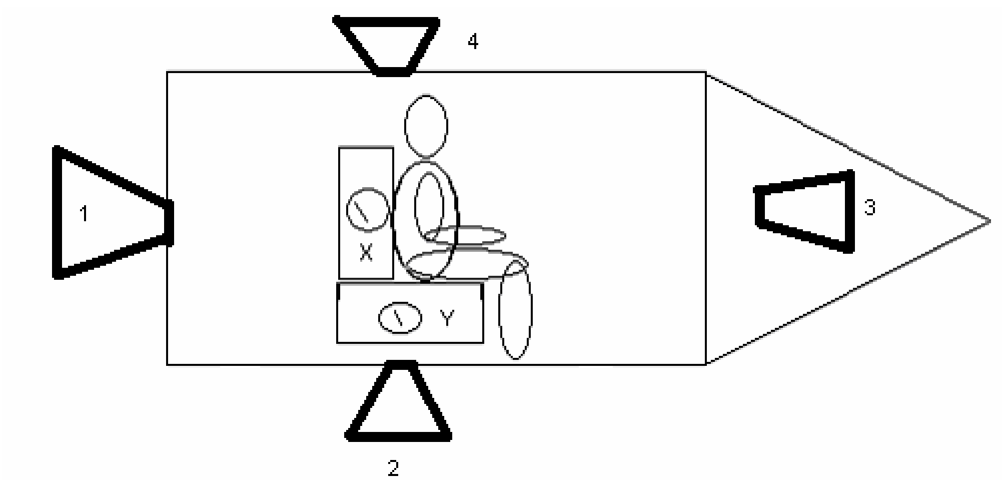
Using New Knowledge – The Elevator Misconception

Appendix J

Using New Knowledge – The Elevator Misconception

Name: ___________________________ ID#: __________________

- Answer the following questions: Consider a passenger sitting in a seat on a rocket equipped with four rockets as shown in the diagram below. The rockets are capable of firing independently or together in various combinations. Each rocket produces the same magnitude of force.
- The seat of the occupant is capable of measuring force on the bottom cushion (y direction) and on the rear cushion (x-direction).
- Please determine if the force would register to the x-direction, y-direction, both or neither directions.
- Initially, the x-meter is registering 0 Newtons and the Y-meter is registering 100 Newtons for the occupant's weight.



1. Firing Rocket #1

X		Y	
Greater than 0 Newtons	_____	Greater than 100 Newtons	_____
Less than 0 Newtons	_____	Less than 100 Newtons	_____
Equal to 0 Newtons	_____	Equal to 100 Newtons	_____

2. Firing Rocket #2

X		Y	
Greater than 0 Newtons	_____	Greater than 100 Newtons	_____
Less than 0 Newtons	_____	Less than 100 Newtons	_____
Equal to 0 Newtons	_____	Equal to 100 Newtons	_____

3. Firing Rocket #3

X		Y	
Greater than 0 Newtons	_____	Greater than 100 Newtons	_____
Less than 0 Newtons	_____	Less than 100 Newtons	_____
Equal to 0 Newtons	_____	Equal to 100 Newtons	_____

4. Firing Rocket #4 X Y

Greater than 0 Newtons _____ Greater than 100 Newtons _____
Less than 0 Newtons _____ Less than 100 Newtons _____
Equal to 0 Newtons _____ Equal to 100 Newtons _____

5. Firing Rockets #1 & 3 X Y

Greater than 0 Newtons _____ Greater than 100 Newtons _____
Less than 0 Newtons _____ Less than 100 Newtons _____
Equal to 0 Newtons _____ Equal to 100 Newtons _____

6. Firing Rocket #1 & 2 X Y

Greater than 0 Newtons _____ Greater than 100 Newtons _____
Less than 0 Newtons _____ Less than 100 Newtons _____
Equal to 0 Newtons _____ Equal to 100 Newtons _____

7. Firing Rocket #3 & 4 X Y

Greater than 0 Newtons _____ Greater than 100 Newtons _____
Less than 0 Newtons _____ Less than 100 Newtons _____
Equal to 0 Newtons _____ Equal to 100 Newtons _____

8. Moving at Constant Speed of V = 100m/s**i** + 0m/s **j**

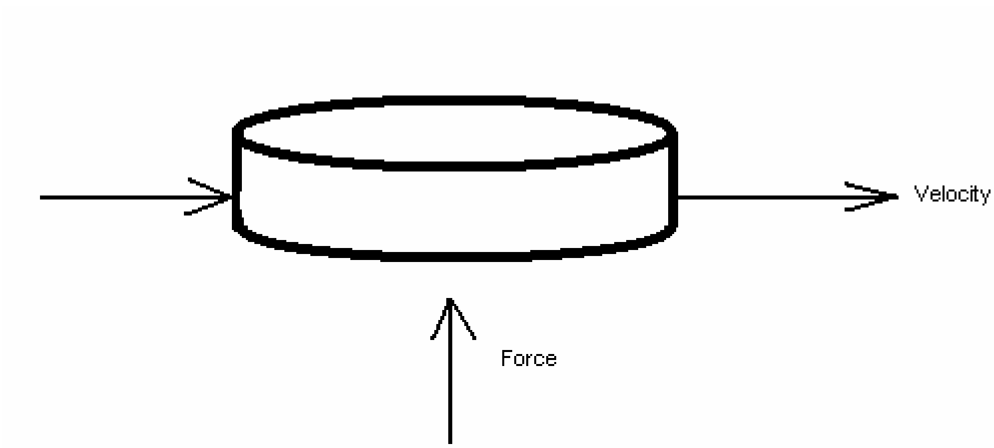
X Y

Greater than 0 Newtons _____ Greater than 100 Newtons _____
Less than 0 Newtons _____ Less than 100 Newtons _____
Equal to 0 Newtons _____ Equal to 100 Newtons _____

Figure 1.

The Hockey Puck traveling in the X-direction and struck by a sudden force normal to the direction of travel.

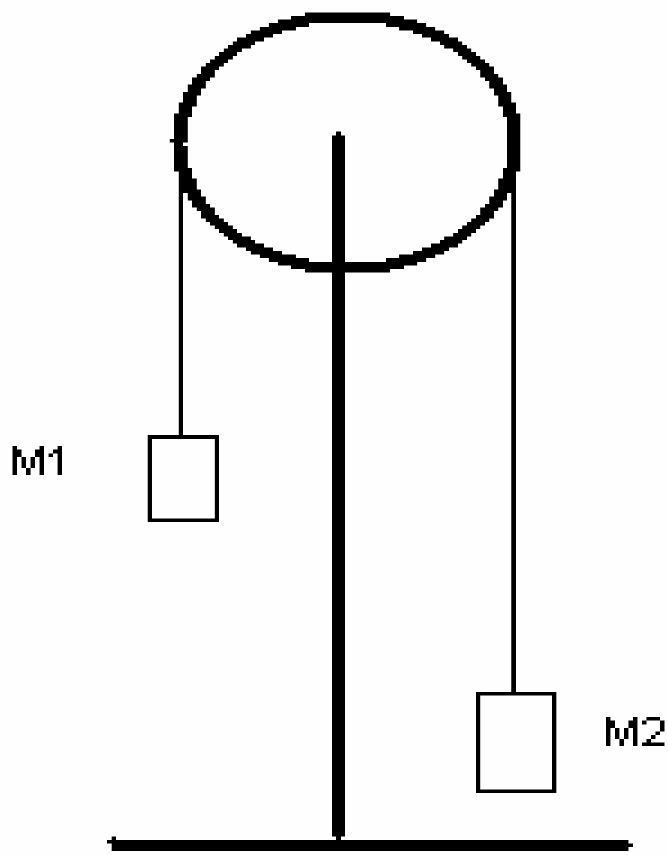
Figure 1. The Hockey Puck



The Hockey Puck is traveling in the X-direction and struck by a sudden force normal to the direction of travel.

Figure 2. The Atwood Pulley

Figure 2. The Atwood Pulley

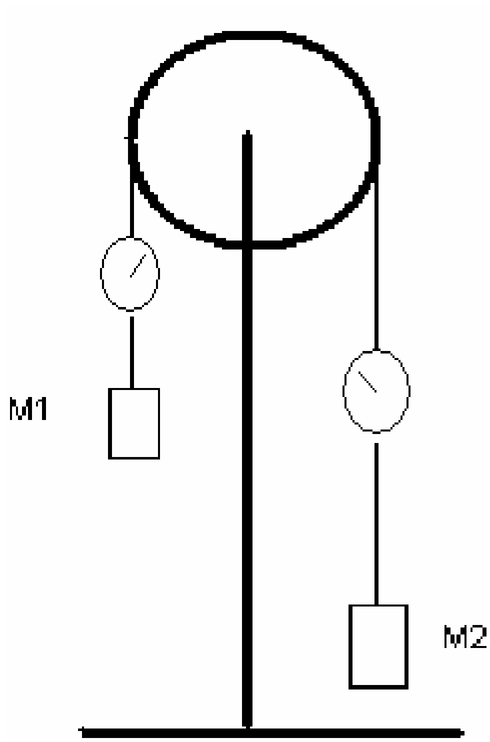


Each of the two masses represents an elevator

.

Figure 3.
The Atwood Pulley – Each mass is supported by a spring gauge.

Figure 3. The Atwood Pulley



Each mass is supported by a spring gauge.

Figure 4.

The Space Vehicle Equipped with Four Rockets

Figure 4. The Space Vehicle Equipped with Four Rockets

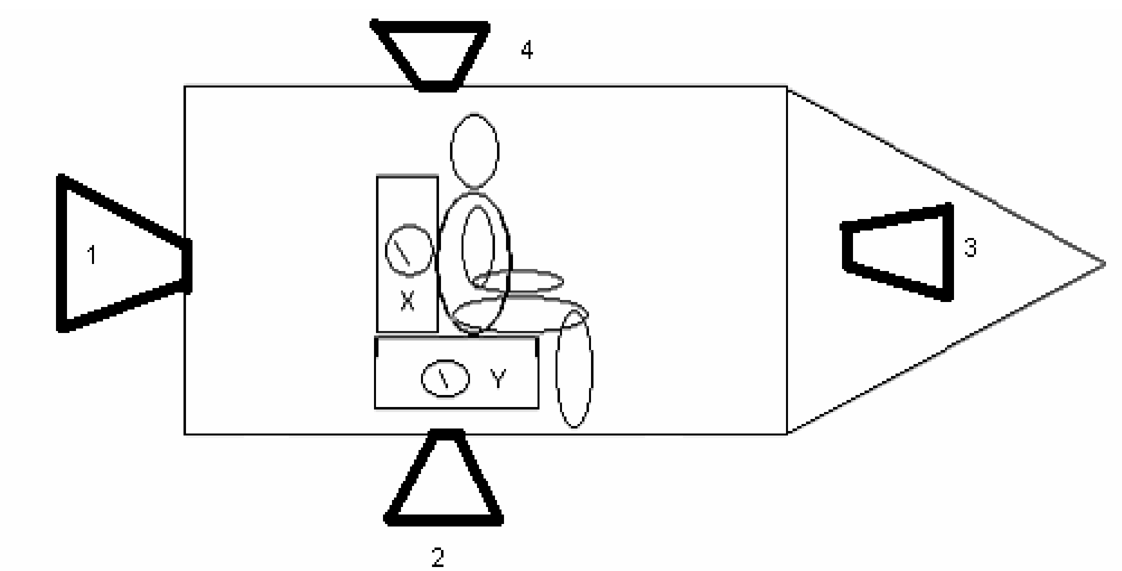
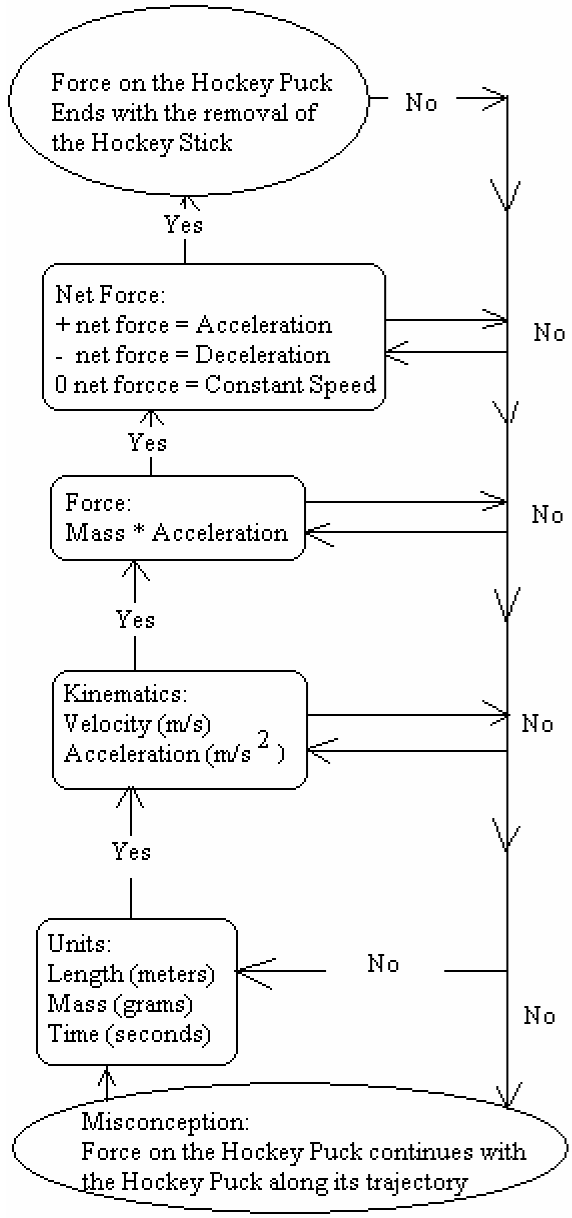


Figure 5 – Concept Map / Flow Chart of the Hockey Puck Hierarchy of Understanding

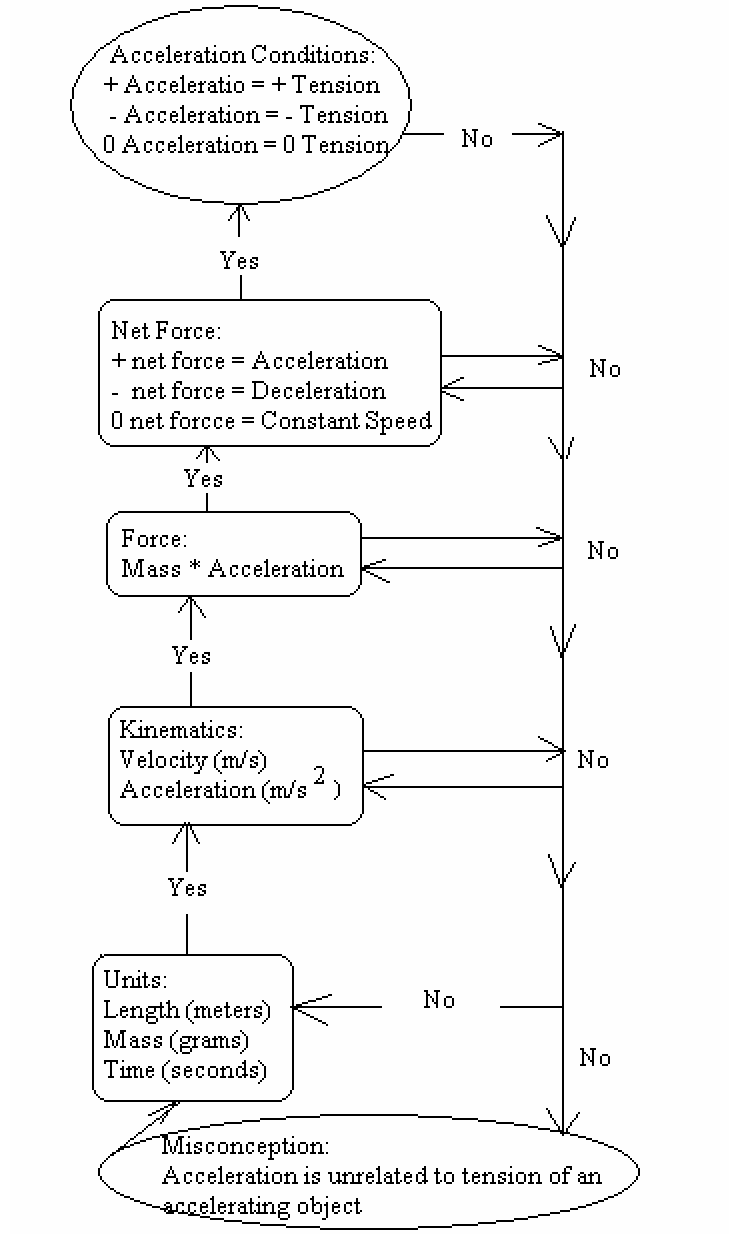
Figure 5 – Concept Map / Flow Chart of the Hockey Puck Hierarchy of Understanding



Yes = The concept is understood by the student; continue to the next concept
No = The concept us not understood by the student; review the previous concept

Figure 6 – Concept Map / Flow Chart of the Elevator Hierarchy of Understanding

Figure 6 – Concept Map / Flow Chart of the Elevator Hierarchy of Understanding



Yes = The concept is understood by the student; continue to the next concept
No = The concept us not understood by the student; review the previous concept

Table 1
Force Concepts Inventory Results

Table 1
Force Concepts Inventory Results

Category	Newtonian Concepts	Inventory Item	Pre*	Post **
Superposition	Canceling forces	9 18	7	19
Kinds of Forces	Air resistance	22	8	15
Kinds of Forces	Friction opposes motion	22	8	15
Third Law	For impulsive forces	2 11	19	28
Gravitation	Gravitation	5 9 12 17 18 22	21	28
Kinds of Forces	Impulsive	15	21	13
First Law	Speed constant	8	27	32
Kinds of Forces	Passive	9 12	28	37
Kinematics	Velocity and position	20	35	31
Kinematics	Constant acceleration	25	36	34
Kinematics	Vector addition	7	36	34
Second Law	Continuous acceleration	24 25	36	31
Kinematics	Constant acc. par. orbit	23 24	41	30
Second Law	Impulsive force	6 7	41	42
Kinematics	Acc./ vel. discrimination	21	44	55
Kinds of Forces	Buoyant (air pressure)	12	47	55
First Law	Velocity direction const.	12	47	55
Kinds of Forces	Acc. indep. of weight	1 3	48	39
First Law	With no forces	4 6 10	56	54
Kinds of Forces	Parabolic trajectory	16 23	57	51
Third Law	For continuous forces	13 14	60	51
Superposition	Vector sum	19	63	52

* The number of students who chose the correct pretest response for this Newtonian Concept
**The number of students who chose the correct posttest response for this Newtonian Concept
109 students completed the pre test
102 students completed the posttest

Table 2

Summary of Conceptual Change Associated with CCM

Table 2
Summary of Conceptual Change Associated with CCM

CCM Perquisites	Hockey Puck Successful Conc. Change	Hockey Puck Unsuccessful Conc. Change	Elevator Successful Conc. Change	Elevator Unsuccessful Conc. Change
Dissatisfaction	A			
Intelligible	A B C	DE	G	I J
Plausible	A B C	D	G	J
Fruitful	B	D	G	J

A = Aaron B = Benjamin C = Caleb D = Doug E = Edward
F = Fred G = Gary H = Harold I = Isaac J = Jack

Table 3
Summary of Conceptual Change Strategies Associated with the Conceptual Change Model

Table 3
Summary of Conceptual Change Strategies Associated with the Conceptual Change Model

Conceptual Change Strategies	Hockey Puck Successful Conc. Change	Hockey Puck Unsuccessful Conc. Change	Elevator Successful Conc. Change	Elevator Unsuccessful Conc. Change
Awareness	A B C	DE	G	F J
Evaluation	A B C	DE	G	F H I J
Regulation	A B C		G	
Reflection	A B		G	F H I

A = Aaron B = Benjamin C = Caleb D = Doug E = Edward
F = Fred G = Gary H = Harold I = Isaac J = Jack

Table 4
Summary of Misconceptions

Table 4
Summary of Misconceptions

Misconceptions	Pre-Discrepant Event	Post-Discrepant Event
Hockey Puck is moving under an impetus Force	A B C D E	D E
Equal masses suspended from the Atwood Pulley self-level	A C E	E
Relationship between Net force and acceleration	A B	
Acceleration and speed are synonymous	D E	
Momentum is a force	B	
Inertia is a force	D	
Acceleration if a force	D	
Force creates movement	C	
Gravity does not generate force	B	

A = Aaron B = Benjamin C = Caleb D = Doug E = Edward
F = Fred G = Gary H = Harold I = Isaac J = Jack

Table 5
Perceptions of Difficulty of Conceptual Comprehension

Table 5
Perceptions of Difficulty of Conceptual Comprehension

Level of Difficulty of the concept	Hockey Puck Successful Conc. Change	Hockey Puck Unsuccessful Conc. Change	Elevator Successful Conc. Change	Elevator Unsuccessful Conc. Change
7				F
6		E		
5	C	D		
4				H I
3	B		G	J
2	A			
1				
0				

A = Aaron B = Benjamin C = Caleb D = Doug E = Edward
F = Fred G = Gary H = Harold I = Isaac J = Jack

Table 6
Summary of Misconceptions (Elevator)

Table 6
Summary of Misconceptions (Elevator)

Misconceptions	Pre-Discrepant Event	Post-Discrepant Event
Relationship of opposing forces and acceleration	F G H I J	F G H J
Force creates motion	F G H I	F G I
Definition of acceleration	G H I	I J
Momentum = force	H	
Mass is the magnitude of an object’s weight	F	

F = Fred G = Gary H = Harold I = Isaac J = Jack

Table 7

Summary of Hierarchy of Knowledge Needed to Undergo Conceptual Change

Table 7
Summary of Hierarchy of Knowledge Needed to Undergo Conceptual Change

Concept	Hockey Puck Successful Conc. Change	Hockey Puck Unsuccessful Conc. Change	Elevator Successful Conc. Change	Elevator Unsuccessful Conc. Change
Units	A B C		G	
Velocity	A B C		G	
Acceleration	A B C	E	G	H
Force	A B C	D	G	
Newton's Laws	A B C	D	G	I

A = Aaron B = Benjamin C = Caleb D = Doug E = Edward
F = Fred G = Gary H = Harold I = Isaac J = Jack