University of Cincinnati

Date: 9/22/2016

I, Jonathan Engelman, hereby submit this original work as part of the requirements for the degree of Doctor of Philosophy in Educational Studies.

It is entitled:

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Student's name: **Jonathan Engelman**

This work and its defense approved by:

Committee chair: Kathleen Koenig, Ph.D.

Committee member: Vicki Plano Clark, Ph.D.

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How College Students' Conceptions of Newton's Second and Third Laws Change Through Watching Interactive Video Vignettes: A Mixed Methods Study

A dissertation submitted to the Graduate School of the University of Cincinnati in partial fulfillment of the requirements for the degree of

Doctor of Philosophy

in the Department of Educational Studies

of the College of Education, Criminal Justice, & Human Services

by

Jonathan Engelman

M.A. Western Michigan University

December 2008

Committee Chair: Kathleen M. Koenig, Ph.D.

Abstract

Changing student conceptions in physics is a difficult process and has been a topic of research for many years. The purpose of this study was to understand what prompted students to change or not change their incorrect conceptions of Newton's Second or Third Laws in response to an intervention, Interactive Video Vignettes (IVVs), designed to overcome them. This study is based on prior research reported in the literature which has found that a curricular framework of *elicit, confront, resolve,* and *reflect* (ECRR) is important for changing student conceptions (McDermott, 2001). This framework includes four essential parts such that during an instructional event student conceptions should be *elicited*, incorrect conceptions *confronted*, these conflicts *resolved*, and then students should be prompted to *reflect* on their learning. Twenty-two undergraduate student participants who completed either or both IVVs were studied to determine whether or not they experienced components of the ECRR framework at multiple points within the IVVs.

A fully integrated, mixed methods design was used to address the study purpose. Both quantitative and qualitative data were collected iteratively for each participant. Successive data collections were informed by previous data collections. All data were analyzed concurrently. The quantitative strand included a pre/post test that participants took before and after completing a given IVV and was used to measure the effect of each IVV on learning. The qualitative strand included video of each participant completing the IVV as well as an audio-recorded video elicitation interview after the post-test. The qualitative data collection was designed to describe student experiences with each IVV as well as to observe how the ECRR framework was experienced. Collecting and analyzing data using this mixed methods approach helped develop a

more complete understanding of how student conceptions of Newton's Second and Third Laws changed through completion of IVVs and how the ECRR framework was experienced.

In answering the research questions, two major conclusions were reached: (1) while the ECRR framework was experienced in both the Newton's 2nd Law and Newton's 3rd Law IVVs, these experiences were qualitatively different from each other and these differences help support the differences in gain scores on the post-tests for the participants; and (2) both IVVs were able to change certain misconceptions associated with either Newton's 2nd or 3rd laws more than others. Therefore, in researching student experiences while completing the Newton's 2nd Law and Newton's 3rd Law IVVs, I determined that a complete, sequential experience of the *elicit, confront, resolve, reflect* framework led to the greatest change in student conceptions.

This dissertation adds to the field of physics education through finding the positive impact of the ECRR framework, as IVVs are still being created and disseminated. Physics educators and researchers interested in conceptual change can use these findings to provide evidence on what students think when interacting with videos designed to change their conceptions. Finally, this dissertation supports the conceptual change literature in that the full, sequential experience involving each component of the ECRR framework led to a change in student conceptions.

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amazing to see what doors God has opened and closed over the past decade as I have been on this dissertation journey. I am so glad to have finally found where He wanted me to complete my degree and work professionally both during and after completing it.

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Chapter 1: Introduction

Introduction and Rationale

Changing student conceptions in physics is inherently difficult to accomplish (Clement, 1982; Hammer, 1996, McDermott, 1990a; 1991; Redish, 2003). Misconceptions and conceptual change in physics education have been widely studied (Chi, 2005, 2008; Chi & Slotta, 1993; Chi, Slotta, & de Leeuw, 1994; di Sessa, 1993, 2008; Dole & Sinatra, 1998; Dykstra, 1992; Hewson & Hewson, 1984; Posner, Strike, Hewson, & Gertzog, 1982; She, 2004; She & Liao, 2010; Taasoobshirazi & Sinatra, 2011; Vosniadou, 1994). Results from this literature suggest that students still exhibit many misconceptions even after instruction, and thus, changing student conceptions in physics is difficult to accomplish on a lasting basis (McDermott, 1990a; Vosniadou, 1994). Researchers have studied specific misconceptions related to many topics in physics, including Newton's laws (Boyle & Maloney, 1991; Kim & Pak, 2002; Maloney, 1984; Thornton & Sokoloff, 1998). Students struggle to learn physics, and typically leave physics class with incorrect conceptions of physical concepts, such as Newton's Laws. Physics education researchers have explored many of these misconceptions over the past few decades, but researchers are still faced with students not understanding key concepts. Physics education has focused great attention on this problem, but more research needs to better educate students (Beichner, 2009).

One instructional framework designed to help overcome student misconceptions in physics is that of *elicit, confront, resolve, reflect* (ECRR) (McDermott, 1991; 2001; McDermott & Shaffer, 2002) and is related to Posner, Strike, Hewson, and Gertzog's (1982) Conceptual Change Model. The ECRR technique has been found to yield positive results to student learning through face-to-face instruction (Allen, 2010; Miller, Lasry, Chu, & Mazur, 2013). However, the

ECRR technique is a fairly new framework applied to the design of instruction using technologies.

One form of instructional technology that includes some of the components of ECRR is that of Interactive Video Vignettes (IVVs) (Laws, Willis, Jackson, Koenig, & Teese, 2015). The LivePhoto Physics Group created IVVs in an attempt to counter misconceptions commonly held by students in introductory physics. IVVs have been created and distributed for Newton's three laws, projectile motion, conservation of momentum, circular motion, and electrostatics, with more topics under development. A single IVV combines segments of video interspersed with moments of interaction such as graphing activities or multiple-choice questions. In some of the IVVs, these video segments and points of interaction are intended to *elicit* prior information, *confront* any incorrect conception, *resolve* this conflict, and then have the students *reflect* on the process. Each IVV lasts 5-8 minutes or more, depending on how long the student takes to complete each interaction point and watch each video segment. Some IVVs were created with the ECRR framework explicitly in mind, such as the Newton's Third Law IVV, while other IVVs were created with the ECRR framework implicitly in mind. While early research on the effectiveness of IVVs is ongoing, what is unknown is howt conceptual change appears as students complete IVVs and how students interact with different components of the ECRR framework as they complete a given IVV (Laws, Willis, Jackson, Koenig, & Teese, 2015). The focus of this dissertation centered on how student conceptions of Newton's Second and Third Laws changed through completing two Interactive Video Vignettes and how they experienced the ECRR framework embedded in each.

The Newton's Second Law IVV takes approximately 11 minutes to complete. During these minutes, a participant watches multiple videos of accelerating carts, answers two multiple choice questions predicting motion or relationships between variables, and creates a few velocity versus time graphs based on videos they watched. The ECRR framework was not used explicitly in the design of this IVV, but rather, any experience a participant has with the framework comes out implicitly. The Newton's Third Law IVV takes approximately eight minutes to complete. During these minutes, a participant watches multiple videos of colliding cars or carts, answers two multiple choice questions, and observes how bystanders in the videos react to watching the collisions. The ECRR framework was explicitly used in the creation of this IVV, and so participants' experience this framework more explicitly.

The LivePhoto Physics Group has conducted quantitative studies on the effectiveness of each IVV (Laws, Willis, Jackson, Koenig, & Teese, 2015), as measured by the Force Concept Inventory (FCI) (Hestenes, Wells, & Swackhamer, 1992). Since the IVVs were each created with the idea of countering strongly held misconceptions, the research thus far has concentrated on the effectiveness towards this end. Their initial findings suggest that students enjoy using IVVs but that their use outside of class does not necessarily increase student learning for all IVVs (Laws, Teese, Jackson, Willis, & Koenig, 2013). The LivePhoto Physics Group has used the FCI as a pre- and post-test and Hake's gain (Hake, 1998) as its quantitative statistic to measure the effectiveness of each IVV, comparing groups of students that completed IVVs with groups that received regular physics instruction without IVVs. The LivePhoto Physics Group has found a medium Hake's gain for the Newton's Third Law IVV, but low Hake's gain for the Newton's Second Law IVV (Laws et al., 2015). Since each IVV was designed to counter incorrect student conceptions, yet each has thus far not impacted student learning the same, the purpose of this dissertation was to understand what could be causing students to hold on to their incorrect conceptions in response to an intervention designed to overcome them. This dissertation sought to find evidence of the ECRR framework as found in student experiences with each IVV in order to better understand why the Newton's Third Law IVV is more effective at changing student conceptions while the Newton's Second Law IVV does not change student conceptions to the same degree.

Purpose Statement

The purpose of this study was to understand what prompted students to change their conceptions of Newton's Second or Third Laws through completing Interactive Video Vignettes, as informed by the *elicit, confront, resolve, reflect* framework. A fully integrated, mixed methods design was needed so that the dialogue between the different data forms could lead to greater insights into the conceptual change process (Teddlie & Tashakkori, 2009). In this research design, both quantitative and qualitative data were collected iteratively for each participant, with each successive data collection informed by the previous data collection. Quantitative and qualitative data for all participants in the study were analyzed concurrently. The quantitative strand included a pre/post test that participants took before and after completing a given IVV and was intended to measure the effect on learning using Hake's gain. The qualitative strand included video of the student completing the IVV and then a video elicitation interview after the post-test. The qualitative data collection was designed to describe student experiences with each IVV as well as to see how the ECRR framework was experienced during each IVV. Collecting and analyzing data in this way helped develop a more complete understanding of how student conceptions changed through completion of IVVs and how the ECRR framework was experienced.

Research Questions

The overall question this study sought to answer was *How effective are elicit, confront, resolve, and reflect in promoting changes in student conceptions of Newton's Second and Third Laws through completion of Interactive Video Vignettes?* This question was addressed through the following quantitative, qualitative, and mixed methods questions.

Quantitative Question

1) What effect do Interactive Video Vignettes have on student conceptions of Newton's 2nd and 3rd laws?

Qualitative Questions

2) How do student experiences with Interactive Video Vignettes facilitate conceptual change?

3) How are *elicit, confront, resolve,* and *reflect* experienced by students while completing the Newton's 2nd Law and Newton's 3rd Law Interactive Video Vignettes?

Mixed Methods Question

4) How do qualitative descriptions of similarities and differences in student ECRR experiences relate to quantitative changes in student conceptions? What other explanations of these similarities and differences emerge?

Significance

Design and use of technology such as IVVs are promising for changing student conceptions, but clear knowledge and methods gaps exist regarding their effectiveness at creating conceptual change. The creation of IVVs was informed by research on the use of videos and other technologies throughout the last few decades (Grayson & McDermott, 1996; McDermott, 1990b; Muller, 2008). Research into the effectiveness of IVVs by the LivePhoto

Physics Group has thus far only used quantitative methods and has not yet used mixed methods as a research design. Two research areas in particular helped inform the study of the effectiveness of IVVs pertaining to conceptual change: the structure of linear videos and points of interaction within technology. The structure of videos drew on the research of Muller, while the points of interaction came from the work of Escalada and Zollman and others.

Recent work by Muller (2008) was of particular importance to the development and study of IVVs, both due to his ability to disseminate his videos to millions of viewers through YouTube as well as the videos' ability to overcome student misconceptions in physics. Not only this, but he also helped in the filming and creation of one IVV (Bullet in the Block). Muller found a specific structure of video and multimedia technology that fosters positive conceptual change—linear video that includes specific reference to incorrect conceptions (Muller, 2008). Much of his work was conducted through a quantitative lens, meaning he was interested in determining the statistical effect video had on student learning. Students participating in his studies watched his videos as passive observers, rather than as active participants within different parts of the video. Thus, Muller's work did not include any study of how students interacted with videos while watching them.

Interactive videos allow students opportunities to engage with video as an active, rather than a passive, participant. While watching interactive video, students come to points of interactions within the videos where they stop and complete a graph, answer a question, or complete an activity (Aiken et al., 2014; Escalada & Zollman, 1997). Students tend to learn more through using interactive videos rather than traditional instruction (Beichner, 1996; Singh, 2008; Wehrbein, 2001). In work by Escalada and Zollman (1997), structuring videos to include points of interaction between students and videos has yielded positive results in terms of student learning.

This dissertation pulled together past research on conceptual change in physics with pedagogical-uses of video, specifically Muller's work with linear multimedia and Escalada and Zollman's work with interactive video, to explore how students and their conceptions of Newton's Second and Third Laws interact with the IVVs. Drawing from this work, video played in a linear fashion, that contains explicit references to misconceptions while also incorporating places within these video sequences where students will interact with the video, should lead to changes in their conceptions. As mentioned earlier, the LivePhoto Physics Group found that the Newton's Third Law IVV is able to change student conceptions of Newton's Third Law, while the Newton's Second Law IVV does not change student conceptions more than regular instruction. These results are surprising in that Muller's work suggests that video containing explicit references to misconceptions should positively impact learning, as should video containing points of interaction. This dissertation sought to accomplish two goals: (1) determine the extent to which two IVVs (Newton's 2nd and 3rd Laws) change student conceptions of Newton's Second and Third Laws and (2) identify, understand, and depict the characteristics of these two IVVs that change or do not change student conceptions of Newton's 2nd and 3rd Laws, since each IVV may apply the ECRR framework differently. These IVVs were explored in first-year college students using a fully integrated mixed methods design (Teddlie & Tashakkori, 2009).

With the possibility of a growing number of institutions using and creating their own IVVs, it is critical that researchers and teachers better understand the learning students do when completing IVVs, whether their conceptions actually do change through using IVVs, and how the IVVs actually help student learning. The LivePhoto Physics Group has provided online access to multiple IVVs, including Newton's 2nd and 3rd Laws, on the COMPADRE website (http://www.compadre.org/IVV/). This allows instructors around the world to incorporate these IVVs in their own teaching. The findings of this dissertation have the possibility of being quite valuable to the field of physics education as well as to the LivePhoto Physics Group as they continue to create and disseminate more IVVs. For example, future designs of IVVs could incorporate a sequential structure of the ECRR framework around specific misconceptions students typically hold of a given topic. The IVVs have recently been disseminated at a national conference (Laws et al., 2014), and a popular physics educator journal (Laws et al., 2015) and thus, many institutions and instructors might find IVVs beneficial to their physics students. Physics educators could use the findings from this study to help shape future creation of IVVs as well as *elicit* what students think when interacting with a video activity designed to change their conceptions.

Definitions of Terms

This section outlines various words or phrases that have specific meanings that are useful to reference prior to the remaining chapters of this dissertation.

Alternative conception: An alternative conception is students' knowledge that does not match with accepted, scientific views of a given topic (Clement, 1993).

Conceptual change: Conceptual change is defined as learning that transforms the way an individual knows something (Chi, Slotta, & de Leeuw, 1994; Duit & Treagust, 2003; Vosniadou, 2008). As students learn new information, they must find a way to accommodate this new information within their previous learning. When a student replaces a previous incorrect conception, or misconception, with the correct conception, conceptual change has taken place.

Convergent parallel design: This type of mixed methods design occurs when a quantitative and qualitative strand are conducted at approximately the same time. Priority is equal between the two strands. Analysis of each strand is conducted independently from each other. Results from each strand are mixed prior to overall interpretation of the study (Creswell & Plano Clark, 2011).

Epistemology: Epistemology describes the nature and development of knowledge. Applied to conceptual change, epistemology describes how students develop various concepts (Chi, Slotta, & de Leeuw, 1994; Kang, 2007).

Integration: Integration occurs when the quantitative and qualitative data are mixed to determine how both data sets describe the phenomenon in question (Creswell & Plano Clark, 2011).

Interaction Point: An interaction point occurs when students have opportunities to engage with the video itself while watching it. These points of interaction occur when the video stops and the student must complete some sort of analysis, such as create a graph on the computer from video data (Aiken et al., 2014; Escalada & Zollman, 1997). In the case of interaction points in an IVV, this must be completed prior to continuing on with further video in the IVV.

Interactive Video Vignette (IVV): Interactive Video Vignettes combine active-learning strategies from physics education research with an online delivery system. Created by the LivePhoto Physics Group, IVVs are short (5-7) minute web-based interactive activities that require students to make predictions about real-world situations followed by video analysis of these situations.

Linear Video: Linear video contains a single video, where the viewer can only start and stop. There are no interactions within the video itself (Muller, 2008).

LivePhoto Physics Group: The Live Photo Physics Group created the two IVVs studied in this dissertation. This group is supported by the National Science Foundation and includes Priscilla Laws, David Jackson, and Maxine Willis at Dickinson College, Robert Teese at Rochester Institute of Technology, Patrick Cooney at Millersville University, and Kathy Koenig at the University of Cincinnati.

Meta-inference: As part of a mixed methods study, meta-inferences are conclusions drawn from the combined data sources as well as any conclusions derived from transformed data (Creswell & Plano Clark, 2011).

Misconception: A misconception can be any conception students hold that is not in agreement with the accepted scientific view. However, this term is not always considered a positive term and in fact can instead be used for alternative conceptions students hold that are not in agreement with accepted scientific knowledge that are simultaneously very robust and resistant to change (Redish, 2003).

Mixed methods research: Mixed methods research combines the use of both quantitative and qualitative research methods in a single study such that the phenomena under study are better understood than when researched using a single research method (Creswell & Plano Clark, 2011; Greene, 2007; Morse & Niehaus, 2009; Tashakkori & Creswell, 2007).

Multimedia: Multimedia includes any combination of visual media, such as diagrams, graphics, animations, video, and sound (Fuller, 1993; Muller, 2008). Linear multimedia occurs when participants use it in a passive fashion and played from start to finish without stopping (Muller, 2008). Non-linear multimedia occurs when participants use it in an active fashion and requires points of interaction between the multimedia and the participant (Aiken et al., 2014; Escalada & Zollman, 1997).

Newton's Second Law: Newton's Second Law states that the force on an object is directly proportional to its mass. This law is stated as F=ma: Force equals mass times the acceleration of the object.

Newton's Third Law: Newton's Third Law states that when one object exerts a force on another object, the second object exerts the same force on the first object, but in an opposite direction. Another way of stating this law is as follows: For every action (force) there is an equal and opposite reaction (force).

Ontology: Ontology is a means by which knowledge can be classified. Applied to conceptual change, ontology describes the concepts students know and learn (Chi, Slotta, & de Leeuw, 1994; Kang, 2007).

Phenomenography: Phenomenography is the study of the different ways people interpret a shared experience. As opposed to phenomenology, which is the search for the lived experiences of a phenomenon, phenomenography assumes that people will experience things differently and seeks to find all of these different experiences (Bodner, 2007; Marton, 1981).

Physics Education Research (PER): Physics education research is a field that merges education research with physics research and historically has contained bench scientists who also conduct educational research without as formal training in educational research methods as an educational researcher. The current trend in the field is to train new researchers who have a content specialty in physics that have graduate degrees in educational research (Beichner, 2009).

Preconception: Preconceptions are students' conceptions they bring to the classroom prior to instruction (Clement, 1993).

Priority: Priority is a term of importance to mixed methods research. Priority describes the relative importance of one research strand over the other, such as prioritizing the quantitative strand over the qualitative strand. In the case of this dissertation, priority is equal. Neither the quantitative nor the qualitative strand is more important than the other (Creswell & Plano Clark, 2011).

Radical restructuring: Also known as radical conceptual change, this occurs when students' existing knowledge structures are changed and restructured at their core, i.e., accommodation (Duit & Treagust, 2003; Dykstra, 1992; Harrison, Grayson, & Treagust, 1999).

Student conception: What a student thinks, believes, knows, or understands about a topic.

Timing: Timing is a term of importance to mixed methods research and refers to when different parts of each strand occur in relation to each other. Sequential timing refers to collecting and analyzing one component before another or completing one strand before another. Concurrent timing refers to collecting and analyzing data for each strand around the same time (Creswell & Plano Clark, 2011).

Validity: Validity refers to the overall quality of conclusions and interpretations found from a study (Creswell & Plano Clark, 2011). Specific strategies to be used in order to increase the quality of conclusions and interpretations are outlined in the methods section of this proposal.

Video: Video is a recording of continuously moving images and comes in a few different forms, such as through a digital recording or a videocassette. Video will be used in two different ways in this dissertation. The first way is through a digital video camera that captures video footage that can then be transferred to a computer hard drive for future video analysis as well as the video elicitation interview. The second way comes in the form of a web link where each participant will watch pre-recorded, edited videos.

Video elicitation interview (VEI): A video elicitation interview takes place when a research participant is asked questions while watching video of him/her completing an intervention. In the case of this dissertation, the intervention is an IVV. The purpose of an elicitation interview is to elaborate on an experience in the past while looking at photos or a video of these experiences (Henry & Fetters, 2012).

Weak restructuring: Also known as weak conceptual change, this occurs when new facts are assimilated into students' existing knowledge structure, i.e., assimilation (Duit & Treagust, 2003; Dykstra, 1992; Harrison, Grayson, & Treagust, 1999).

Summary

In this chapter, I have introduced the problem and purpose of this dissertation research addresses. Changing student conceptions in physics is a difficult process and has been a topic of research for many years. The purpose of this study was to understand what prompted students to change or not change their incorrect conceptions of Newton's Second or Third Laws in response to an intervention, Interactive Video Vignettes (IVVs), designed to overcome them. In the chapters that follow, I review the literature used to formulate this study, the methods used to answer the research questions asked in this chapter, show the results, and discuss the implications of these results.

Chapter 2: Literature Review

Introduction

This chapter reviews literature from a number of topics: the methodological worldview that provided a foundation for the study, the two theoretical frameworks and one analytical framework that informed data analysis, literature that informed a better understanding of the use of videos, misconceptions that informed the data analysis, and personal experiences that impacted all areas of this dissertation. Each of the topics covered in this chapter help motivate the methodology, data analysis, and conclusions reached in this dissertation.

Worldview

This study proscribed to the multiple paradigms thesis (Teddlie & Tashakkori, 2009). This position holds that multiple paradigms help serve different strands of a mixed methods study. For this fully integrated mixed methods design, a post-positivist paradigm was used to help guide the quantitative strand of the study. Post-positivism as a worldview values cause and effect, control of variables, theory testing, and careful measurement (Creswell & Plano Clark, 2011; Teddlie & Tashakkori, 2009). For this study, a post-positivism worldview was especially useful in encouraging impartiality when collecting quantitative data as well as to test the hypothesis that IVVs will benefit student learning. However, the number of participants was small and the analysis of the data was very descriptive, two issues that posed a challenge to post-positivist thinking.

For the qualitative strand of this study, post-positivism was not a useful paradigm. The video elicitation interviews themselves created partiality and bias, two concepts post-positivism seeks to minimize (Creswell & Plano Clark, 2011). Not only that, but the qualitative strand was informed by the results of the quantitative data. Specifically, the qualitative strand of this study examined how students created new knowledge and conceptions as these characteristics were being created and changed. Each student participating with the elicitation interviews had their own unique experience with the IVVs. The process of conducting research was in this regard rather deductive, as opposed to the usual inductive nature of most qualitative research. As such, some themes found in the qualitative data drew heavily on looking for specific misconceptions participants held after watching IVVs, along with the thinking associated with these misconceptions and what experiences with the ECRR framework looked like in practice. There were certainly themes that were drawn out of the data in an inductive manner, but not all themes were discovered in this way. Thus, while constructivism (Creswell & Plano Clark, 2011; Teddlie & Tashakkori, 2009) was useful for certain components of this study, it certainly was not the only paradigm informing the qualitative strand of this dissertation.

When the quantitative and qualitative were mixed, integrated, and analyzed as a whole, a third paradigm was used: pragmatism. As a worldview, pragmatism is concerned with collecting and analyzing data in such a way as to answer the mixed methods research questions (Cresewell & Plano Clark, 2011). This paradigm does not ignore the paradigms associated with the methods. Rather, it relies on what each method, and its associated paradigms, brings to the research process. This means that pragmatism can comfortably combine data considered biased and unbiased or data that shows a single reality or multiple realities. In using pragmatism in this way, I enacted the multiple paradigms thesis.

Theoretical Frameworks

Multiple theoretical frameworks were used to shape the design of the data analysis of this dissertation. The first theoretical framework, dealing with conceptual change, helped inform the design of the analysis of both the quantitative data and the qualitative data and helped answer RQ 1 and RQ 2. This theoretical framework drew from one of the earliest research on conceptual change: the conceptual change model, or CCM (Hewson & Hewson, 1984; Posner, Strike, Hewson, & Gertzog, 1982). These two models of conceptual change expanded on the *elicit, confront, resolve, reflect* framework the LivePhoto Physics Group used when creating some IVVs (Laws et al., 2014) and helped inform the analytical framework used in analyzing the quantitative and qualitative data in order to answer RQ 3. Not only that, but according to the National Research Council (2000),

> Students come to the classroom with preconceptions about how the world works. If their initial understanding is not engaged, they may fail to grasp the new concepts and information that are taught, or they may learn for purposes of a test but revert to their preconceptions outside the classroom (pp. 14-15).

The frameworks used in this dissertation attempted to address this charge by the National Research Council. Further research from conceptual change in physics education was drawn upon to help describe various student misconceptions throughout this study. This research is described in detail in Chapter 3.

The second theoretical framework was used to shape the design of the qualitative strand of this study. In matching the qualitative research questions to a theoretical framework, the theory of phenomenography was used (Bodner, 2007; Marton 1981). Phenomenography "is the empirical study of the limited number of qualitatively different ways in which various phenomena in, and aspects of, the world around us are experienced, conceptualized, understood, perceived, and apprehended" (Marton, 1981, p. 95). Put in a different way, the aim of phenomenography is to "elucidate the different possible conceptions that people have for a given phenomenon" (Orgill, 2007, p. 133). In the case of this dissertation, the central phenomena which phenomenography helped uncover were the characteristics of the IVVs that affect student conceptual change and how the participants interacted with these characteristics differently. Phenomenography, then, helped answer RQ 2 and RQ 3.

Conceptual Change: The Conceptual Change Model

Expanding on Piaget's theory of cognitive conflict, assimilation, and accommodation, Posner et al. (1982) and Hewson and Hewson (1984) developed an epistemological theory of conceptual change, the Conceptual Change Model (CCM), which suggests that in order for students to change their conceptions, four things must take place: (1) students must be dissatisfied with their current misconception, (2) a new conception must be able to be grasped, (3) a new conception must be plausible, and (4) a new conception must be able to be expanded on for future learning. In this view, a student's alternative conception must be replaced by a new conception, thus ridding the student of their old, incorrect conception. Typically, applying this framework requires a situation where the teacher or instructor finds a means by which to cause cognitive conflict in the student through a discrepant event. The goal is to replace the old information with the new, either through Piaget's assimilation or accommodation. One underlying belief comes from constructivism—that students construct their own knowledge (Hewson & Hewson, 1984). In order for number 2 to occur, students must not only know the meaning of the concept, but also be able to describe it in their own words (Duit & Treagust, 2003). For number 3 to occur, students must believe that the new information is correct and that their old information is not (Duit & Treagust, 2003). For number 4 to occur, students must be able to apply the new information in new situations or problems (Duit & Treagust, 2003). The overall goal in conceptual change for this model is to replace the old, incorrect information with the new, correct information.

In applying this framework, some IVVs were designed to use McDermott's *elicit, confront, resolve, reflect* (ECRR) framework (McDermott, 1991; 2001; McDermott & Shaffer, 2002). This framework is one means by which the CCM can be applied in classrooms (Allen, 2010). IVVs are intended to *elicit* initial student conceptions, be they correct or incorrect. With an initial conception *elicited*, an IVV attempts to *confront* any misconceptions regarding a given topic. It is at this point that the IVV tries to cause the student to be dissatisfied about their misconception. The IVV *resolves* this conflict by offering a new conception that should be easily grasped, plausible, and expandable. Finally, the IVV offers opportunities for students to *reflect* on the previous ECR sequence. This dissertation used this framework to determine the characteristics of an IVV that cause students to change their conceptions.

The authors of the CCM readily admit that obtaining accommodation of the new, correct information is difficult and that using conceptual conflict will not always work to do so. They further suggest that if a student holding an alternative conception is unable to *resolve* conflict between the new correct information and their current understanding, no conceptual change will occur (Hewson & Hewson, 1984). McDermott (1990a) points out that strongly held beliefs are difficult for students to give up. The key, then, is to make the new ideas understandable and convincing to students. The four-step theory of the CCM is necessarily hierarchical—the first step must occur before the second, and so-on. One of the challenges facing physics instruction, then, is the first step—students must be dissatisfied with current misconceptions. This is sometimes quite difficult. Since students oftentimes learn physics as a set of many different pieces of disconnected information (Reif, 1987) rather than group related sets of information together in chunks (National Research Council, 2000; Redish, 2003), that new knowledge has little structure to it (van Heuvelen, 1991). Thus, many students come to physics class with misconceptions they believe in. The pedagogies teachers apply in the classroom must begin with helping students order and structure their new knowledge (van Heuvelen, 1991).

This theory of conceptual change has also been well used in science and physics education (Tao & Gundstone, 1999). As it began to be used, however, researchers found a few limitations to the theory. One distinct limitation was the lack of a connection to motivation, or the affective domain (Allen, 2010; Treagust & Duit, 2008). Why should a student want to change their conception? Their conception of how the world works still works for them, so why should they change it? The affective domain has been a fairly recent addition to the conceptual change research (Treagust & Duit, 2008). This theory also does not contend with any social aspects of learning (Allen, 2010). Based on these limitations, the authors updated the theory to include a social component (Strike & Posner, 1992). By adding this component, the impact of social aspects of learning, such as within groups, was explored by these authors.

Additionally, this theory of conceptual change outlined the requirements for conceptual change, rather than the pieces of pedagogy to create it (Shiland, 1997). Studies that applied the model as an instructional one intended to create instances in cognitive conflict in students, which does not always cause conceptual change (Caravita & Hallden, 1994; Dega, Kriek, & Mogese, 2013; Lee et al., 2003; Maloney, 1984; Redish, 2003; Schwedes & Schmidt, 1992; Vosniadou, 1994a). Sometimes students simply see these conflicts as anomalies that do not apply in every case (Caravita & Hallden, 1994). Frequently, an exercise intended to cause cognitive conflict goes unrealized to the student. To the student, their preexisting knowledge works when explaining the physical world around them (Hammer, 1996). If they are not aware of conflict between old and new information, they will not attempt to reorganize the two in their head through either accommodation or assimilation. In order for cognitive conflict to cause conceptual change, students must be made aware of the conflict (Caravita & Hallend, 1994; Redish, 2003). Students must question their beliefs, turning the situation of cognitive conflict into one of disequilibration (Dykstra, 1992) but do so in such a way that they can move the new information from short-term, working memory into long-term memory (Redish, 2003). To do this, they must *reflect* on both their preconceptions as well as their new conceptions and make connections between the two explicit and to extend their learning to new situations (Harrison, Grayson, & Treagust, 1999; Tao & Gunstone, 1999). In addition, the complexity of alternative conceptions suggests that cognitive conflict is not always achieved, thus decreasing the impact of the cognitive conflict (Dega, Kriek, & Mogese 2013).

The Conceptual Change Model helps inform the process by which students went through to change their conceptions while watching an IVV. As Chapter 4 will show, students must have a conceptual conflict in their mind on order to give up their current misconception in favor of the correct conception. If they are not dissatisfied with their misconception, or they do not realize that their misconception is incorrect, they will have no desire to replace it with the correct conception. Thus, the students researched in this study actually follow the four steps of the Conceptual Change Model in order to change their misconceptions.

Phenomenography

In designing the qualitative phase of this study, phenomenography helped shape the methods of collecting and analyzing the data. The primary means of data collection for phenomenography is an interview carried out in the form of a dialogue between the researcher and the research participant (Marton, 1994), has been used relatively frequently in physics education (Ayene, Kriek, & Damtie, 2011; Madsen, Larson, Loschky, & Rebello, 2012; Walsh, Howard, & Bowe, 2007), and in one case, to study conceptual change (Hrepic, Zollman, & Rebello, 2010). The interview questions asked by the researcher tend to emerge from the interview, with few questions prepared in advance (Marton, 1994; Orgill, 2007). The ideal sample for interviews is one of maximal variation (Orgill, 2007). A maximal variation, where the participants are sampled to gain the most variation in experience, is best suited to elicit the variations in conceptions required in a phenomenography (Ayene et al., 2011). Once all interviews have taken place, the data are analyzed in such a way as to find what Orgill (2007) calls "categories of description" (p. 133). These descriptions identify the limited number of conceptions as well as their meanings (Orgill, 2007). The methods section of this proposal will outline more in-depth the structure of qualitative data collection and analysis techniques.

Analytical Framework

ECRR Framework

The ECRR framework consists of four components: *elicit, confront, resolve, and reflect*. These four pieces combine the *elicit, confront, resolve* framework of McDermott (1991, 2001) with the need to *reflect* on learning (McDermott, 2001; Tao & Gunstone, 1999). This last piece, *reflect*, can be found throughout the conceptual change literature as being crucial to the conceptual change process (Caravita & Hallden, 1994; Rowlands, Graham, Berry, & McWilliam, 2007; Tao & Gundstone, 1999) and was not initially a component to the early versions of this framework. In her later work, McDermott (2001) adds *reflect* as a component of the ECR cycle.

Early conceptual change literature called for teachers to work through a sequence of events in the classroom in order to bring about conceptual change. Nussbaum and Novak (1982) call for a similar structure to the CCM that teachers should create exposing events that invoke student preconceptions, encourage a *confrontation* within student knowledge through making a discrepant event, and then finally, encourage students to accommodate the new knowledge into their original knowledge. McDermott (1991a) would later use this structure and give it the name *elicit, confront, resolve* in simplifying the language. In this framework, pre-misconceptions students hold coming into the classroom need to be *elicited*. These incorrect conceptions, then, get *confronted* through dialogue to help correct the incorrect reasoning. This process should then lead to a *resolve* of the conflict.

One key to McDermott's early framework working is that students must be made aware of the conflict in their thinking. In other words, if a student's thinking has not been *confronted*, the misconception may not be changed (Schwedes & Schmidt, 1992). Students must believe that the intended instance of *confront* really does conflict with their thinking. Otherwise, there is nothing for the student to *resolve* in their thinking.

A missing piece to McDermott's early ECR framework is that of *reflect*. Tao and Gunstone (1999) assert that students must *reflect* on their thinking in order for the conceptual change to take place. Others in the conceptual change literature reiterate this point (Caravita & Hallden, 1994; Rowlands, Graham, Berry, & McWilliam, 2007). *Reflections* must include thinking about the entire process of the ECR framework. McDermott later added this component to the ECR sequence (McDermott, 2001). Thus, the supposition of this dissertation is that a framework of *elicit, confront, resolve, reflect* should be a more complete structure to the conceptual change process. Within this dissertation, then, the ECRR framework was used to analyze student experiences with the Newton's Second and Third Law IVVs to discover how students experience each component through the process of their conceptual change.

Muller and Multimedia Videos

One of the most popular means by which to share video is through YouTube. One very popular channel for physics, as shown by around 4 million subscribers and nearly 300 million views, is Veritasium. This YouTube channel was created and is organized and updated by Derek Muller. His recent work on multimedia-use outside of the physics and science classroom is beginning to take hold and affect change to how we can better teach (Muller, 2008; Mayo, Sharma, & Muller, 2009; Muller, Bewes, Sharma, & Reitmann, 2008; Muller, Sharma, Eklund, & Reitmann, 2007; Muller, Sharma, & Reimann, 2008). This work spanned two distinct physics topics: Newtonian mechanics and quantum mechanics. Since the design of multimedia for the purpose of promoting student learning of physics is an ever-changing area of research, Muller intended to understand the challenges with the design of effective multimedia (Muller, 2008). Defining multimedia to include any combination of words and pictures in order to create a single message, Muller was able to include many different types of instructional materials in the definition of multimedia, including illustrations in textbooks, diagrams, animations, and videos (Muller, 2008).

Muller's work ultimately attempted to find the most effective forms of linear multimedia for increasing student learning, specifically, counteracting student misconceptions. Linear multimedia contains a single video, where the viewer can only start and stop. There are no interactions within the video itself. The multimedia was designed from the cognitive theory of multimedia learning (Mayer, 2001), constructivism, and misconceptions research. Muller wanted to test different types of multimedia presentations and different ways of presenting alternative conceptions and why they are incorrect.

Muller created three phases of research. The first phase centered around developing two multimedia presentations in quantum mechanics. One multimedia presentation consisted of video of an individual giving an explanation of a quantum mechanics topic in a style similar to a lecture. The second multimedia presentation showed a tutor and a student dialoging about the same topic. In measuring the differences of learning for students who received either treatment, Muller found statistically significant results that the dialogue treatment was better at teaching the students (Muller, 2008; Muller et al., 2007).

Muller's next two phases centered around Newtonian mechanics. In the first Newtonian phase, Muller created four multimedia treatments: refutation, dialogue, exposition, and extended exposition. The refutation treatment included explicit statements to refute a given incorrect conception. The dialogue and exposition treatments were similar in design to those treatments in phase one, aimed at either dialoguing or explaining why an incorrect conception is incorrect. The extended exposition treatment added further information beyond the outcomes being measured. Muller found that the refutation and dialogue treatments out-performed the exposition and extended exposition treatments (Muller, 2008; Muller et al., 2008).

In the final phase, Muller replaced the extended exposition with a worked examples treatment. This phase also measured perceived mental effort. Muller found that dialogue treatment outperformed the other treatments (Muller, 2008; Muller et al., 2008). He also found that students perceived greater mental effort while completing the dialogue treatment (Muller, 2008; Muller, Sharma, & Reimann, 2008). In other words, students thought harder during the dialogue treatment, but this harder thinking did not negatively impact their learning; rather, it may have actually increased their learning.

Muller's work yielded two important findings. The first was that, of the parameters he investigated, the most effective multimedia presentations in terms of student learning gains should contain a dialogue between individuals in the video (Muller, 2008). Within the dialogues was the second important finding—the dialogues should contain explicit reference to and discussion of misconceptions (Muller, 2008; Muller et al. 2008; Muller, Sharma, & Reimann, 2008). Muller concluded that these results are quite useful, since video is likely to continue to be used more as an instructional tool, especially with more education being offered online (Mayo, Sharma, & Muller, 2009; Muller, Sharma, & Reimann, 2008).

I see clear connections between Muller's work and IVVs. For instance, the Newton's third law IVV incorporates a similar structure to Muller's dialogue multimedia treatment. The Newton's third law IVV shows dialogues between an interviewer and a number of bystanders. The video brings out the most frequent alternative conception with collisions—when two objects of different masses collide, the smaller mass experiences the greater force during the collision. This IVV explicitly addresses the alternative conception with measurements from a lab video that show that the forces are equal in magnitude, but opposite in direction. Muller's work suggests that this sort of structure should achieve significant learning gains. The Newton's second law IVV does have a brief period of dialogue between two students and an interviewer about what will happen when a force is applied to the cart. The early portion of the Newton's second law IVV is the only case within the IVV that includes dialogue between people within the video. The remaining portions are highly interactive, in that students will plot velocity versus time points to obtain graphs, make predictions on what the acceleration will be if the mass is doubled, and create further graphs. These remaining portions of this IVV are expository in nature. Discussion of alternative conceptions regarding Newton's second law exist, but are less obvious than the treatment of alternative conceptions in the Newton's third law IVV. Muller (2008) found that expository multimedia was not as successful as dialogue or refutation, thus suggesting that the Newton's second law IVV may not have as significant learning gains as the Newton's third law IVV.

Pedagogical Uses of Video Technology

Physics education has long used video and visual media to help teach physics (Zollman & Fuller, 1994). These include the analysis of video discs, such as the Tacoma Narrows Bridge and other interactive videos (Fuller, 1993b; Zollman & Fuller, 1994). The interactivity was programed into the videodiscs themselves: students could scan a barcode and move to different points within the video in order to take data and create graphs (Fuller, 1993a, 1993b, Zollman & Fuller, 1994). Fuller (1993a, 1993b) terms these multimedia, in that they include graphics, video, animation, and sound. Students had control of the analysis themselves, could pause the video at any point, move the video forward or backward frame by frame, in order to better understand the applications of physics to things students can see outside of the classroom (Zollman & Fuller, 1994). Other videos students could analyze were the wind resistance of a bike rider in a wind tunnel, a crash-test dummy crashing into an air bag during a car accident, or a high jumper (Zollman & Fuller, 1994). Watching videos in this way allowed students to watch and take measurements of a high jumper change the shape of their body to make it over the bar, or see how the head collides with an air bag. Encouraging students to look at video in this way encourages more active learning and give better context to what students learn in physics classes (Fuller, 1993a).

Other forms of video interactions were developed around the same time that encouraged intuitive, individualized instruction (Larsen, 1992; Hoffer, Radke, & Lord, 1992). Results from early physics education research were being used to inform the development of such programs (McDermott, 1990; Reif, 1987). For instance, computer programs that students would use to interact with videos needed to ensure students became intellectually involved and stimulated (Grayson & McDermott, 1996; McDermott, 1990). The way buttons were placed on the screen, or where hypertext was placed, was thought-out (Hoffer, Radke, & Lord, 1992). Poor design of these could hinder student learning. Computer programs have been designed to both elicit and refute students' preconceptions of a given topic (Goldberg & Bendall, 1995; Gorsky & Finegold, 1992). Student cognition and ideas about why students think the way they do began to inform instructional design (Reif, 1987). Videos on computers began to inform and change student thinking (Grayson & McDermott, 1996; Weller, 1995).

Much of this early work on videos and multimedia did not incorporate technology in the same ways as IVVs. Interactions and analysis of video were not necessarily completed using technology. For instance, when analyzing a video to create a graph, students could move a video forward frame by frame, and place pieces of acetate on the screen to create the graph. These graphs, then, were not necessarily created with the same computer program that controlled the video. The Newton's Second Law IVV instead has this type of graph created within the IVV, and the graph shows up in electronic form on the computer screen. However, the foundations for the continual development of video-use had begun. Over time, programs to analyze video included features that help students interact in more complicated ways (Beichner, 1990; Chen, Stelzer, & Gladding, 2010; Thornton & Sokoloff, 1990). What students could analyze, such as graphing, or how students learn best, has impacted many different applications of multimedia to physics classrooms. In the sections that follow, I review many of these applications to see this development.

Interactive Video

Interactive video allows students opportunities to engage with video in an active, rather than a passive, manner. While watching interactive video, students come to points of interactions within the videos where they stop and complete a graph, answer a question, or some other activity (Aiken et al., 2014; Escalada & Zollman, 1997). In the case of interaction points in an IVV, this must be completed prior to continuing on with further video in the IVV. With interactive video, students actually do manipulation of the video, rather than just see the video with a graph simultaneously (Brungardt & Zollman, 1995; Escalada & Zollman, 1997; Etkina, 2010; Williamson, Torres-Isea, & Kletzing, 2000). Students tend to learn more through using interactive videos rather than traditional instruction (Beichner, 1996; Singh, 2008; Wehrbein, 2001). Not only that, but interactive video allows the analysis of video from outside the laboratory setting, meaning that laboratory equipment is not necessary in order to collect any data in the first place (Escalada & Zollman, 1995). Videos from the real world can help students better connect physics to their everyday experiences (Escalada & Zollman, 1995; Singh, 2008; Leonard, 2015; Wehrbein, 2001). Using videos interactively can also help students consume more information in a shorter period of time than through in-class presentations and experiments (Etkina, 2010). Students are even better able to *confront* their graphing misconceptions to better interpret those experiences (Beichner & Abbott, 1999). With the ability to play the video at any speed, or move back in time to replay what students just saw, interactive video analysis can be a very powerful tool for conducting video analysis (Beichner & Abbott, 1999; Etkina, 2010; Lessie, 2000; Wittman, Morgan, & Feeley, 2006). Also, with the ever-changing technology, this can be applied to online situations, so that students can access the tools from anywhere (Nakamura, Murphy, Zollman, Christel, & Stevens, 2010; Singh, 2008).

The Newton's second law IVV contains numerous instances where a student can interact with a video. For every video in the IVV, a student can replay that video as many times as they wish. Students are even prompted to do so on multiple occasions. For instance, a student may wish to watch the short video clip of the cart accelerating, prior to answering the question about what the shape of the speed versus time graph will look like. Students also get to actually make three different speed versus time graphs during this IVV. In each case, students plot a point that is a speed and time coordinate, and do so frame by frame from the video by clicking on the cart itself. The analysis software embedded within the IVV will not allow the students to plot the points incorrectly. In other words, the student must click on the appropriate part of the cart in order to plot the point correctly. This way, the graph is guaranteed to be linear, but it forces the student to click on the same part of the cart in every frame. In the Newton's third law IVV, students do less actual interacting with the videos that they see because they do not collect any data or make any graphs. However, they are able to replay any video they see over again should they wish to do so.

Common Misconceptions Pertaining to Newton's Laws

Over the course of the last 35 years or so, physics education has spent considerable time and publishing space exploring student conceptions, especially that of Newtonian mechanics. The research on student understanding of Newton's laws is extensive and highly descriptive, allowing me to more easily classify the misconceptions found in the participants. This section gives an overview of the major alternative conceptions found over the last 35 years. Alternative conceptions are particularly pervasive in Newtonian mechanics because students can often recite Newton's laws from memory, but do not understand how to apply the laws, and frequently exhibit some of the following alternative conceptions regarding their application (Brown & Hammer, 2008; Dykstra, 1992).

General Misconceptions Regarding Forces

Before going into specific misconceptions found in Newton's Second and Third Laws, there are some general misconceptions regarding forces that were reviewed. These misconceptions generally relate to a lack of complete understanding of forces and have specific implications in other misconceptions found in Newton's Second or Third Laws.

Impetus. Perhaps the most well-known and published alternative conception found in all of physics education is the idea students have about force where any moving object contains a force (Chi, Slotta, & de Leeuw, 1994; Champagne, Klopfer, & Anderson, 1980; diSessa, 2007; Dykstra, Boyle, & Monarch, 1992; Galili & Bar, 1992; Ozdemier & Clark, 2009; Reiner, Slotta, Chi, & Resnick, 2000; Shymansky et al., 1997; Tao & Gunstone, 1999; Vosniadou, 1994). This conception implies that force can be considered a physical characteristic of an object. The plethora of research mentioning impetus suggests that impetus pervades student learning of Newtonian mechanics. When students exhibit this conception, they perceive any object that has motion as having a force contained within it that keeps the object moving. This conception is particularly robust (Galili & Bar, 1992) and very difficult to change.

Motion implies force. A related conception to impetus is that of the concept that motion implies an applied force (Boyle & Maloney, 1991; Champagne, Klopfer, & Anderson, 1980; Clement, 1982; Finegold & Gorsky, 1991; Galili & Bar, 1992; Ozdemier & Clark, 2009; Shymansky et al., 1997; Tao & Gunstone, 1999). In this alternative conception, students assume that any moving object must have an applied force on it. This conception is different than the impetus conception. For impetus, the object itself provides the force that causes motion. The motion implies force conception suggests that any moving object has an external force being applied on it.

Force as a physical object. In this alternative conception, students believe that force is actually a physical object rather than a process of interaction (Boyle & Maloney, 1991; Ozdemier & Clark, 2009; Reiner, Slotta, Chi, & Resnick, 2000). This conception relates directly to Chi's ontological categories, where the problem solving abilities and knowledge of both novices and experts were organized and classified (Chi & Slotta, 1993; Chi, Slotta, & de Leeuw, 1994). The correct category for force is that of a process, while students tend to place it in the matter category. Thus, changing this classification is quite difficult to achieve.

Absence of forces. Another frequent alternative conception relates to objects when there is an absence of applied forces. In many cases, students assume that when an applied force is removed from an object, causing the net force to be zero, the object will not move or will slow down until it stops (Champagne, Klopfer, & Anderson, 1980; Thornton, 1997). Again, this relates to students' experiences in reality, where an object will eventually slow down due to frictional forces. While this is a correct interpretation of what happens when taking those external forces into account, students are unable to dissociate this knowledge from simpler systems where friction and wind resistance is ignored. In other words, students can have difficulty applying Newton's second law correctly.

diSessa's p-prims. According to diSessa's (1993) work on p-prims, there are six distinct p-prims regarding Newtonian mechanics. P-prims are a description of the physics phenomena that takes into account students' prior naive learning and are useful in simple situations.

Force as mover. The force as mover p-prim, begins with a stationary object that is pushed. It then moves in the direction of the push. Physicists actually use this p-prim themselves, for simple situations. However, students tend to extend this p-prim to situations where the object pushed is already moving. What happens in this case is the object gets deflected, and the resulting motion is neither in the direction of the original motion nor in the direction of the push.

Force as spinner. The force as spinner p-prim is the rotational equivalent to force as mover. Students understand that when a round object is pushed, it will roll or spin. This is the force as spinner p-prim. However, students often inaccurately apply this p-prim in situations that it should not be used. Imagine looking at a yo-yo from the side, with part of the string to the right. If the string is pulled to the right, students think the yo-yo will roll to the left, when in fact it will roll to the right. They apply the force as spinner p-prim, when they really should apply the force as mover p-prim**.**

Continuous push. The continuous push p-prim extends the force as mover p-prim, which is a sudden and brief application of force, to a more lengthy application of the force. In the continuous push p-prim, an object has an applied force on it for a set period of time, longer than a brief moment. For instance, pushing a block across a table by applying a force during the entire movement, versus hitting the block once—the force as mover p-prim. This p-prim is also applied incorrectly by students many times, to situations where a box is carried across a room. Students tend to see the box moving and assume there is a force at play, while ignoring any energy that is being added to the system and not taking into account any momentum of the system.

Constraint phenomena. Several physics concepts students learn prior to entering the classroom are classified as constraint phenomena. These include bouncing, blocking, supporting, guiding, and clamping. For instance, students innately understand that if a ball is thrown at a wall, the wall will prevent the ball from entering it (unless the wall was incredibly weak at that point). In applying the clamping p-prim, for instance, students will assume that an object sandwiched between two equal and opposite forces will not move. However, in interpreting the situation in that way, they would be ignoring the fact that no net force can also mean that the motion is not changing. Another example comes with the blocking p-prim. A cup that lies stationary on a table has two equal and opposite forces acting on it, one from gravity, and one from the Newton's third law pair. In other words, gravity pulls the cup down, and the table pushes back, preventing the cup from entering the table. Students typically do not see the table as pushing, because they apply the force as mover p-prim and assume that if the table is pushing on the cup, then the cup must be moving. Since the cup is not moving, there must not be a force coming from the table. Again, there is nothing incorrect about the p-prim, but when applied to more complex or different situations, it may not work.

Newton's Second Law Misconceptions

Five distinct misconceptions were found in the literature regarding Newton's Second Law. Each of these is summarized as follows.

Force causes acceleration to terminal velocity. In this misconception, students believe that when a constant force is applied on an object, this force will cause the object to accelerate at a constant rate until the object reaches terminal velocity, at which point the velocity will be constant (Hestenes, Wells, & Swackhamer, 1992). One way of looking at this misconception is when a student applies a correct interpretation of falling objects to horizontal motion. For instance, a student could have the correct conception that a falling object under the influence of gravity will reach a terminal velocity if given enough initial height. When applying this to a horizontal situation with a constant force, though, terminal velocity is not reached, thus showcasing the misconception.

Acceleration equals velocity. Related to the constant force means constant velocity misconception, the acceleration equals velocity misconception occurs when a student confuses acceleration and velocity. For instance, they may be given a situation where it is stated that a problem has a constant acceleration, but the student thinks that acceleration and velocity are the same thing. This could be because they simply do not know the difference between the two or that they really do think they mean the same concept.

Constant force means constant velocity. Many students misinterpret Newton's second law. Instead of relating force and acceleration, students sometimes believe that force and velocity are proportional to one another or that constant force means constant velocity (Bliss & Ogborn, 1994; Champagne, Klopfer, & Anderson, 1980; Dykstra, Boyle, & Monarch, 1992; Eryilmaz, 2002; Tao & Gunstone, 1999; Thornton, 1997). On the one hand, students at least recognize that velocity and acceleration are related, in that acceleration necessitates a change in velocity. However, the incorrect relationship they have between velocity and force relates to the motion implies force conception. If students believe one, they will believe the other. This conception, too, is highly resistant to change (Eryilmaz, 2002).

Motion when force overcomes resistance. This misconception assumes that a constant applied force will only cause an acceleration after the object's resistance to motion has been overcome (Hestenes, Wells, & Swackhamer, 1992). This means that the student believes that force is a physical object and that an object's force must be overcome before it can begin moving. When probed regarding this misconception, students can sometimes say that the force that resists motion is that of the force due to gravity, thus showing they are confusing the different directions of gravitational force and a horizontal applied force.

Active force wears out. This misconception implies that an applied force will end eventually, and thus, the motion will change after that point (Eryilimaz, 2002; Hestenes, Wells, & Swackhamer, 1992). While this is correct given enough time, such as with a rocket, in applying this assumption to a given problem, students actually assume more than the givens in a problem. In other words, they may read that a problem has a constant applied force, but they incorrectly assume that the applied force will not remain constant forever, and instead, die out eventually.

Newton's Third Law Misconceptions

Applications of Newton's third law to collisions show students have further alternative conceptions. Students tend to think that the object with the greater mass causes the greater force (Maloney, 1984; Camp & Clement, 1994). Students forget that in applying Newton's third law to collisions, they must also apply Newton's second law, which will take into account the different masses of the objects colliding. Students even believe that hard objects apply greater forces than softer objects during collisions, and that fragile objects apply less force than more rigid objects (Camp & Clement, 1994). Without being able to actually measure the forces exerted during a collision, it is very difficult to change this conception.

Greater mass implies greater force. In this misconception, it is assumed that during a collision, the object with a larger mass will exert a larger force on an object with a smaller mass (Eryilimaz, 2002; Hestenes, Wells, & Swackhamer, 1992; Maloney, 1984). This misconception can be found whether the objects have the same or different velocities, or whether either the larger or smaller mass is stationary.

Speed and force (acceleration) are equivalent. In the context of collisions, this misconception is found when a speed and acceleration are interchanged without regard to their meaning. Similar to when this is found in Newton's Second Law, for Newton's Third Law this is found in instances where two objects have different speeds and then a student assumes they then have different accelerations. While it could be true that the accelerations might be different, as in the case where two objects of different masses collide, and thus, in applying Newton's Second Law it can be calculated that the two objects have different accelerations during a collision, this is not the interpretation most students take with this situation. Most often, it is simply due to equating the two without extensively exploring the meaning of each term.

Active agent produces the greater force. This misconception is found when a student assumes the object that is moving faster, or is more active, exerts a larger force (Eryilimaz, 2002; Hestenes, Wells, & Swackhamer, 1992)). For instance, if one object is moving at a different speed than another before a collision, this misconception would suggest that the faster object exerts the larger force. This is also found when one object is stationary and one is moving.

Obstacles exert no forces. This misconception is found when a student assumes that a stationary object does not exert a force during a collision (Hestenes, Wells, & Swackhamer, 1992). For instance, if one car is not moving and another runs into it, the moving car exerts a larger force than the stationary car, regardless of the masses of each object. When exploring whether this situation is the obstacles or active agent misconception, one must probe to determine if a student believes the forces are different due to the fact that one object is moving faster or if one object is stationary. Thus, for a given incorrect answer, different misconceptions could be identified.

Personal Experiences

This study is very important to me. Eight years of experiences teaching in middle school and introductory college mathematics and introductory college physics courses suggest that overcoming student misconceptions is a very difficult endeavor and is one of my teaching goals. Students tend to have very strong opinions regarding their conceptions and find it disconcerting when they discover their conceptions are wrong and in some cases refuse to admit that their conceptions are incorrect. Previous studies in physics (Kim & Pak, 2002; National Research Council, 2000) suggest that students tend to hold onto these misconceptions well after a course has completed. The IVVs are a relatively new platform by which student misconceptions can be *confronted* and possibly changed. With smart phones and tablets becoming more prevalent and powerful every year, students have an increasing connection to online sources for learning, including video. This goes well beyond simply passing around funny cat videos. I have used videos periodically in teaching introductory physics in college and have found students to be more engaged with the material.

While conducting a small pilot study, watching students complete IVVs, I was able to observe students completing the Newton's Second or Third Law IVV. After watching each student complete the IVV, I interviewed them afterward to explore further their conceptions, whether or not they actually changed, and what that change looked like. The biggest issue I found was that I did not have a quantitative instrument that measured the conceptual change to the degree I needed in order to probe student thinking after completing the IVV. Creating a longer instrument was one of the more crucial pieces that came out of this pilot study. In this dissertation, using a more in-depth instrument, I have attempted to determine more specifically what conceptions changed as a result of the IVV, and further, how robust that change was.

Summary

In this chapter, many topics have been reviewed that inform the conceptualization and design of the study. In describing my worldview, I have outlined how I conceive all of my different data types interacting with one another. Through reviewing the Conceptual Change Model, I have grounded what it means for a conception to have changed and the process by which this change takes place. Describing the development of the ECRR framework grounds the qualitative analysis and gave me the ability to explore in-depth how students experienced the two IVVs. By reviewing pedagogical uses of video, Muller's video studies, and interactive videos, I have placed IVVs into where they fit in the literature as an additional means by which to convey information designed to change student conceptions. Finally, describing misconceptions found within Newton's Laws was used to inform my thinking in conducting this study. All of these topics helped frame both the methodology as well as the data analysis of this dissertation.

Chapter 3: Methodology

Introduction

This chapter describes the quantitative, qualitative, and mixed methods used to collect and analyze data to answer the research questions asked in chapter 1. After defining mixed methods research, I describe the research design used. Next, I outline how the participants were sampled followed by how the data were collected. Then I describe the quantitative and qualitative analyses. This chapter then ends with the mixed methods procedures, including how conceptual profiles were constructed.

Defining Mixed Methods

For this dissertation, I use the following definition of mixed methods research:

> Mixed methods research is a research design that combines the use of both quantitative and qualitative research methods in a single study such that the phenomena under study is better understood than when researched using a single research method.

Creswell and Plano Clark (2007) wrote of mixed methods research and its combination of quantitative and qualitative methods as providing “a better understanding of research problems than either approach alone” (p. 5). Greene (2007) wrote that mixed methods research helps researchers gain a “better understanding of the phenomena being studied” (p. 13). Morse and Niehaus (2009) posited that MMR can “access some part of the phenomena of interest that cannot be accessed by the use of the first [a single] method alone” (p. 9). Both Creswell and Plano Clark (2007) and Morse and Niehaus (2009) as well as Tashakkori and Creswell (2007) described MMR as combining quantitative and qualitative methods in a single study.

Research Design

A fully integrated mixed methods design was used in this dissertation. In a fully integrated mixed methods design, the quantitative and qualitative strands affected the formation of each other where the integration of the data sets occurs during collection as well as analysis (Teddlie & Tashakkori, 2009). A fully integrated mixed methods design was chosen due to the need to collect both the quantitative and qualitative data simultaneously for each participant in order to better understand the differences in the characteristics of the Newton's Second and Third Law IVVs. Subsequent data collections from participant to participant were then affected by prior initial analyses. Recent research by the designers of the IVVs has found that some of the IVVs yield positive learning gains from the Newton's Third Law IVV but no learning gains from the Newton's Second Law IVV (Koenig et al., 2014; Laws et al., 2014), when compared with a control group that did not complete any IVVs. A fully integrated mixed methods research design was used in this dissertation to better understand how student experiences with those two IVVs may impact their quantitative scores.

Design Overview and Procedural Diagram

See Figure 3.1 for the procedural diagram (Creswell & Plano Clark, 2011) for this study. This figure acts as a guide for how the fully integrated design was conceived and enacted during this dissertation. Twenty-three students were recruited for this study, of which I have 22 complete data sets. These students were volunteers from the student body at a small, private, midwestern medical arts college. Nine participants were in General Physics at the time of this study, six of whom completed both the Newton's Second and Newton's Third Law IVV. Fourteen participants were not currently in physics when they completed their data collections and two of these completed both IVVs. At the beginning of each participant's data collection, the participant took part of the quantitative instrument. Each participant was placed in either the Newton's 2nd or Newton's 3rd track, assigning each participant in an every other format while also ensuring equal numbers of physics students completed each IVV and equal numbers of non-physics students completed each IVV. After completing the instrument the first time, the student was asked to complete the given IVV. In Figure 3.1, the two-way dashed arrow between QUAN Data Collection and QUAL Data Collection shows this. Next, the student was videoed while completing the IVV. The video camera was focused on the computer screen and collected both audio and video data. After completion of the IVV, the participant took the same instrument a second time, thus the left side of the two-way dashed arrow. After completing the instrument for the second time, I scored the questions and calculated Hake's gain, signified by the solid down arrow from QUAN Data Collection to QUAN Data Analysis. Then, each participant participated in a video elicitation interview while watching the video of himself or herself completing the IVV (see appendices B and C). Figure 3.1 shows this through the solid arrow up and to the right from QUAN Data Analysis to QUAL data collection. After each interview was complete, qualitative analysis began. This can be seen in the solid down arrow from QUAL Data Collection to QUAL Data Analysis. After both of these analyses were complete, the mixture of the two data sets commenced. In Figure 3.1, this action is shown through the arrows from QUAN Data Analysis and QUAL Data Analysis to Merge Results. After merging the data for each participant, mixed methods analysis took place at the data sets as a whole, drawing on both data types to answer the research questions, while simultaneously beginning to create joint displays showing mixed methods results (Plano Clark & Sanders, 2015). Data collection occurred across three months in order to collect all participants' data, but across about an hour to collect each participants' data.

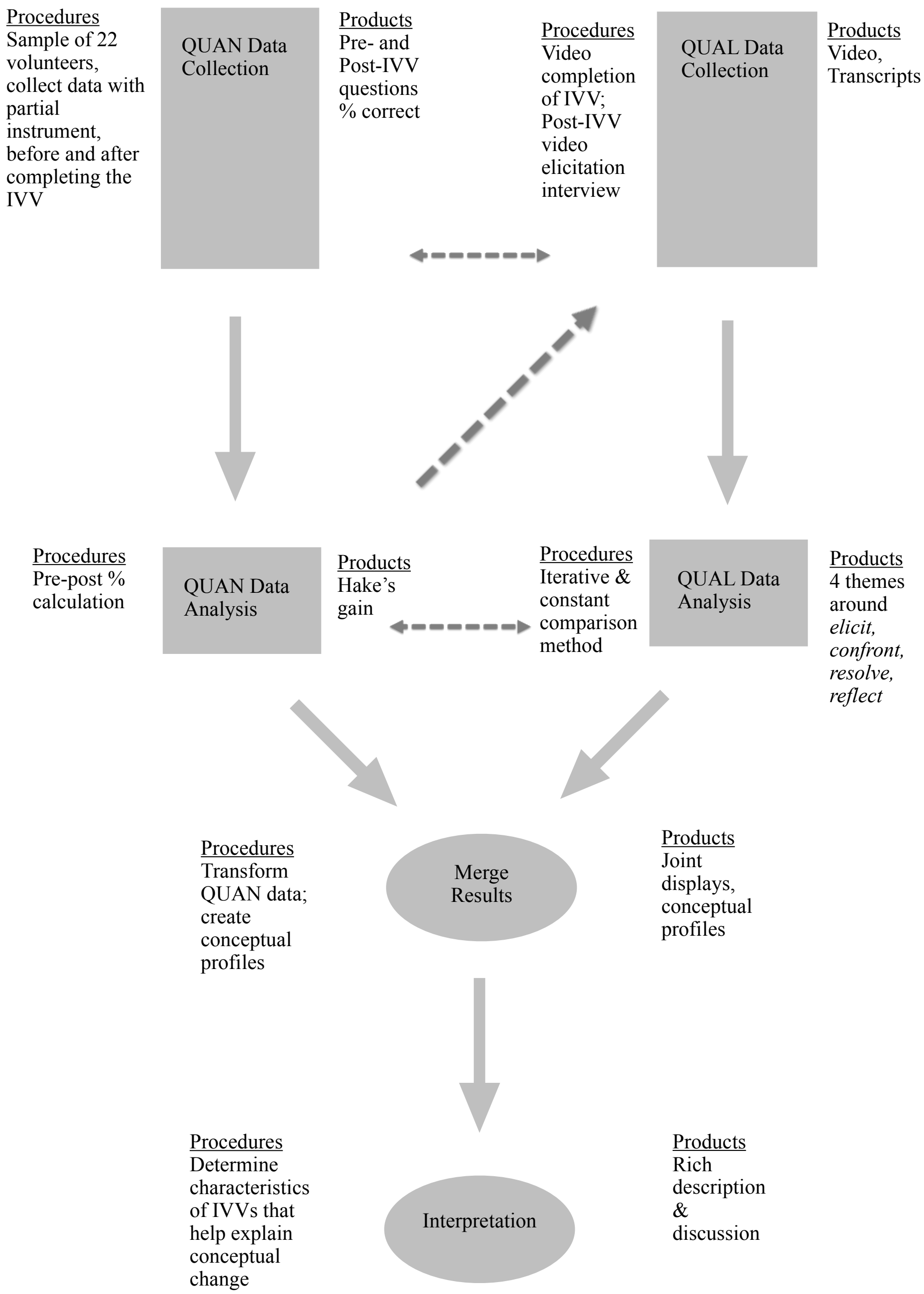

Figure 3.1. Procedural Diagram

Priority and Timing

In describing the relationship of the quantitative and qualitative strands of mixed methods research to each other, the priority given to one strand and timing of each strand to the other help create valid findings in mixed methods research. Priority refers to the relative importance of one strand over the other (Creswell & Plano Clark, 2011). In this dissertation, priority is equal, meaning neither the quantitative and qualitative strand was more important than the other. Rather, they drove each other and "play[ed] an equally important role in addressing the research problem" (Creswell & Plano Clark, 2011, p. 65). In a fully integrated mixed methods design, such priority makes sense, since each strand informs the other at both data collection and data analysis, and thus, they are equal in importance. Both the quantitative and qualitative strands were needed in order to discover the characteristics of the two IVVs that changed or did not change student conceptions.

Timing in a mixed methods study refers to when different parts of each strand occur in relation to each other (Creswell & Plano Clark, 2011). Sequential timing refers to collecting and analyzing one component before another or completing one strand before another (Creswell & Plano Clark, 2011). Concurrent timing refers to collecting and analyzing data for each strand around the same time (Creswell & Plano Clark, 2011). In the fully integrated design used in this dissertation, timing it not as simple as these definitions. For each participant, data collection occurred sequentially, with QUAN, then QUAL, then QUAN, and finally, QUAL. For each participant, QUAN analysis occurred after the second QUAN, and this analysis impacted the collection of the final QUAL. However, for the study as a whole, the data was collected and analyzed in a more concurrent manner. Using the typology found in Morse (1991), this study is thus described as follows: QUAN + QUAL. The capitalization for each strand denotes their equal priority, while the plus symbol denotes the concurrent timing of the data analysis and integration. In designing this dissertation in this way, I purposed to gain a deeper understanding of the effect IVVs had on student conceptions using each strand to help gain more understanding from the other. Bazeley and Kemp (2012) refer to this as "iterative exchange for initiation and development," a generative strategy for integrating quantitative and qualitative data (p. 58). I used this metaphor of *blending*, where the data is integrated in such a way that the understanding created in the process goes beyond what each strand had on its own (Bazeley & Kemp, 2012). In other words, by integrating my data throughout the data collection and initial data analysis process, I allowed the data sets to inform the analysis of the data as a whole and the meanings of the data obtained were much richer as a result.

Setting and Context

The setting for this research was a small, private, midwestern medical arts college. This setting was chosen due to its easy access to me as it is the institution where I work. The students I recruited into the study were easily accessible to me in this setting. The IVVs themselves were not a part of any coursework at this institution so a participant's completion of them was independent of any course requirement.

Sampling

In order to better understand the sample for this dissertation as well as the sampling technique, this section outlines the recruitment methods, how participants consented to the study, describes the participants themselves, and then summarizes the sample as a whole.

Recruitment. Undergraduate students, including students from the general physics course, were recruited to participate. I was not the instructor of general physics, but received permission from the instructor to recruit his students for this study. Enrollment in this course typically ranges between 10 and 25 students. Nine students were recruited into this study via an email and recruitment script (see Appendix D). At the start of the study, I sought around 30 participants, so the numbers in this course were not quite large enough. Thus, I opened up recruitment to any undergraduate student at my institution. This recruitment, through a flier (see Appendix E), brought in an additional 14 participants. All participants were offered a $10 gift card as an incentive to participate.

Consent. Prior to beginning the research study, each student signed a consent form for my records and received a second copy for their own records (see Appendix F for the physics student consent form and Appendix G for the non-physics consent form). The consent form covered both the quantitative and qualitative data collections. All forms, including the consent form, email script, and all data collection tools were approved by the Kettering Medical Center IRB (see Appendix H), with protocol number 778757-2 as well as the University of Cincinnati IRB (see Appendix I).

Participants. While 23 total students participated in this study, one participant's interview was accidently deleted, so there are complete data sets for 22 total participants. Of these, nine were physics students and 13 were non-physics students at the time of their participation in this research study. Seven of the 22 students voluntarily decided to complete both the Newton's Second and Newton's Third Law IVVs, meaning there were 28 total data collections. Fifteen of these collections were for Newton's Third Law, while 13 were for Newton's Second Law. The participants in this study were appropriate to use in this study for a number of reasons. First, they volunteered and were willing to participate. I did not want to coerce any student to participate in the study. Second, by having some participants be non-physics students at the time, this allowed me to compare how a group of non-physics students experienced the IVVs compared to students more familiar with the content. Finally, all the participants were easily accessible to me, making the data collection process easier to accomplish.

Summary. The sample obtained for this study was a convenience sample, since the participants were easily accessible (Creswell, 2012; Patton, 2002; Teddlie & Tashakkori, 2009; Teddlie & Yu, 2007). While Patton cautions that convenience sampling is often not desirable due to the difficulty of these samples not being representative of the population as a whole, Creswell (2012) considers convenience sampling appropriate due to the participants' willingness and availability. The students participating in this study were readily available and willing to participate in both the quantitative and qualitative data collections.

Using a volunteer sample is not unheard of for phenomenographies. For example, Hrepic, Zollman, and Rebello (2010) used volunteers for their study and ended with a sample size of 22 students. Of these 22 students, 16 completed interviews both before and after instruction, six students only completed interviews after instruction, and one student only participated in the before instruction interview. Thus, these 22 students participated in a total of 39 interviews. Bowden et al. (1992) sampled 30 first-year university students and 60 final-year high school students but did not describe how they obtained their sample. In both of these cases, I draw additional conclusions about the appropriate qualitative sample size for a phenomenography. Phenomenographic studies can conduct as many as 90 interviews, though that study (Bowden et al., 1992) had a large research team available to conduct the study. Thus, a sample size of between 20 and 30 total participants was appropriate for this dissertation when compared with other phenomenographical studies in physics education (Bowden et al., 1992; Hrepic, Zollman, & Rebello, 2010; Kuo, 2004; Walsh, Howard, & Bowe, 2010). Since the sampling method used in this dissertation was a volunteer one, I was unable to use a maximal variation sampling technique, which is a technique preferred in phenomenographies (Ayene et al., 2011). That said, I recruited students into the study until the video elicitation interviews stopped yielding unique experiences with the IVVs. In this case, then, the volunteer sample yielded enough data to conduct a phenomonography.

In this dissertation, the quantitative and qualitative samples were the same students. Each student that volunteered to participate in this study completed both quantitative data collections as well as the video elicitation interview. Using participants in both the quantitative and qualitative phases of a mixed method study is more akin to the participant-selection variant of mixed methods data collection (Creswell & Plano Clark, 2011). In this sampling technique, initial quantitative results are used to select participants for the following qualitative data collection. In my case, every participant in the initial quantitative data collection was used for the duration of the study. In the case of the fully-integrated mixed methods design used in this dissertation, this sampling technique allowed each data collection to interact with other data collections within the study.

Data Collection

While typical IVVs take 5-7 minutes to complete (Laws et al., 2014), the Newton's Second Law IVV took most participants around 10-13 minutes to complete while the Newton's Third Law IVV took most participants around 6.5-7.5 minutes to complete. These participations were all recorded on a video camera. The video elicitation interviews, which were audio recorded, ranged from 11.5 to 22 minutes for the Newton's Second Law IVV participants to a range of 5 to 20.5 minutes for participants of the Newton's Third Law IVV. Including the pre- and post-test time, each student participated around 45-60 minutes in total.

Quantitative Instruments

The quantitative strand consisted of a repeated measures quasi-experimental design (Creswell, 2012; Shadish, Cook, & Campbell, 2002). In determining how to measure student knowledge of Newton's Second and Third Laws, I began by looking at the questions that the LivePhoto Physics Group has used in their research thus far (Laws et al., 2015). The test this group uses is a single question written by the group as well as the Force Concept Inventory (FCI) (Hestenes, Wells, & Swackhamer, 1992)[1]. The FCI is test that contains multiple-choice questions only. I decided that at a minimum, I needed to use these same questions. However, I also decided that the questions from the FCI on either Newton's Second or Third Laws might not be sufficient by themselves to measure knowledge of these two topics. Thus, I looked at questions pertaining to these two laws from the Force and Motion Concept Evaluation (FMCE) that pertain to these two laws (Thornton & Sokoloff, 1998). The FMCE contains a mixture of multiple-choice and matching questions. I combined the selected FMCE questions with those already in use by the LivePhoto Physics Group to create the instrument used in this dissertation.

The first 11 questions of my instrument pertained to Newton's Second Law and the last 15 questions pertained to Newton's Third Law. Questions 1 and 2 came from questions 25 and 28 of the FCI. The LivePhoto Physics Group wrote question 3. In this dissertation, these first three questions are referred to as the three LivePhoto Physics Group questions for measuring knowledge of Newton's Second Law. Questions 4-11 came from questions 14-21 of the FMCE. Questions 12-15 came from questions 2, 13, 14, and 11 of the FCI. The LivePhoto Physics Group wrote question 16. In this dissertation, these five questions are referred to as the five LivePhoto Physics Group questions for Newton's Third Law. Questions 17-26 came from

[1] Since the Force Concept Inventory and Force and Motion Concept Evaluation are in the public domain, receiving permission to reprint them in this dissertation is not necessary.

questions 30-39 of the FMCE. For students completing the Newton's Second Law IVV, they took questions 1-11 before and after completing that IVV. For students completing the Newton's Third Law IVV, they took questions 12-26 before and after completing that IVV.

The combination of these 26 questions in their current form has not been validated from a quantitative perspective. However, the FCI and the FMCE have each been validated elsewhere (Halloun & Hestenes, 1995; Huffman & Heller, 1995; Ramlo, 2008). Rather, the 26 questions used in this dissertation have face validity. In chapter 4 I discuss in-depth the challenges I faced with combining these questions in the way that I did.

Qualitative Instruments

The elicitation interviews were conducted through a lens of phenomenography. As such, each interview began with just a few prepared questions. A majority of the questions asked during these interviews emerged during the interview and depended on what the participant did during the IVV (Marton, 1994; Orgill, 2007). In the case of this dissertation, each IVV had a different set of initial questions prepared in advance (see appendices B and C). After a student completed the 11 or 16 question post-IVV test, he or she participated in a short, semi-structured, video elicitation interview. This interview was based on his or her answers to the instrument and how he or she answered questions during the IVV. All of the interview questions were indicative of the questions planned for the interviews, but due to the nature of qualitative research, additional questions emerged related to the topic based on student responses to initial questions.

Review of video elicitation interviews. Video elicitation interviews (VEIs) are a subset of interviews within elicitation interviews. The purpose of an elicitation interview is to elaborate on an experience in the past while looking at photos or a video of these experiences (Bitbol & Petitmengin, 2013; Chen & Ennis, 1995; Felton, Nickols-Richardson, Serrano, & Hosig, 2008;

Hadar, Soffer, & Kenzi, 2014; Otero & Harlow, 2009; Sawtelle, Brewe, Goertzen, & Kramer, 2012; Scheinholtz & Wilmont, 2011). Typically, this interview is audio recorded.

Foundations. There are two different means by which an elicitation interview may be conducted, typically by interviewing participants while looking at photos of an experience (a photo elicitation interview) (Clark-Ibanez, 2004) or while watching a video of an experiences (a video elicitation interview or stimulated recall interview) (Henry & Fetters, 2012; Otero & Harlow, 2009; Sawtelle et al., 2012). In the case of the latter, research participants are video recorded doing something or interacting with stimulus, then later interviewed while being shown the video. While the video may be interesting from a research perspective by itself, researchers are more interested in what participants think about the video (Clark-Ibanez, 2004). The interview itself is intended to elicit information from the participant about the given experience, which may bring out thoughts, beliefs, and emotions about that experience (Henry & Fetters, 2012). In some cases, participants may re-enact the actual experience in the video (Bitbol & Petitmengin, 2013).

Purpose. During a video elicitation interview, the research participants watch a video of themselves interacting with something, with the purpose of finding the perceived and actual effects of what they interacted with (Hadar, Soffer, & Kenzi, 2014). For instance, Henry and Fetters (2012) videoed interactions between doctors and patients. The researchers then showed each doctor or patient (separately) the video of this interaction and interviewed each subject while watching this interaction. In conducting research in this way, the authors were able to delve deeper into the interactions between the patients and doctors that would have been lost otherwise.

Strengths. One major strength of the video elicitation interview is its ability to capture both video of participant experiences as well as participant thoughts and feelings regarding these experiences (Alonzo, Kobard, & Seidel, 2012). The interview itself has the ability to take something somewhat mundane, the video of the experience, and explore what the participants think about that experience (Clark-Ibanez, 2004). These thoughts might not come out with a normal interview, or would remain hidden otherwise (Clark-Ibanez, 2004; Bitbol & Petitmengin, 2013; Henry & Fetters, 2012; Sawtelle et al., 2012).

Limitations. As with many interviews, a distinct limitation to the video elicitation interview lies with the questions asked during the interview itself. Initial questions need to be planned out ahead of time, while not neglecting seemingly trivial questions that may still elicit appropriate information (Hadar, Soffer, & Kenzi, 2014). Also, any questions asked by the researcher must be cognizant of instances where the process might elicit any negative thoughts or feelings from the participants (Clark-Ibanez, 2004). As with other uses of video in research, the video elicitation interview also yields very rich data. Instead of this data being multimodal in the same sense, though, the connections found within the data occur between the interview and the video, rather than within the video itself, adding a new layer to the challenge of analysis, especially the time required to complete the analysis (Clark-Ibanez, 2004; Henry & Fetters, 2012). Data collected during the interview may be participants recollecting their experiences, reliving those experiences, or simply *reflecting* on the experiences (Henry & Fetters, 2012). This means that what the participants say may or may not accurately reflect the experiences, as humans have a tendency to incorrectly construct or misremember their thoughts (Bitbol & Petitmengin, 2013; Henry & Fetters, 2012).

Implications. Henry and Fetters (2012) offer the key steps to conducting a video elicitation interview. The research study mush be adequately conceptualized, meaning the research questions must dictate that a video elicitation interview must be an appropriate method to use in order to answer it. The participants and the setting must be chosen such that sufficient trust and consent be obtained in order to be able to collect the required video and interview data. The process of data collection and storage is crucial. A high-quality, reliable video camera must be used and a process of collecting the actual video data must be created. For instance, the video camera must be able to collect adequate video to be able to show back to the participants. The time between the video recording and the elicitation interview should be minimized in order to increase the likelihood that the participants accurately remember their thoughts and feelings from the video itself. The structure of the elicitation interviews needs to be carefully thought out. Some questions need to be created prior to the interview, but the interviewer must be trained to be able to ask spontaneous questions as well. During the elicitation interview, the interviewer needs to know that it is appropriate to stop the video at any time to ask questions of the participant, or wait for the participant to finish their thoughts regarding a specific sequence within the video. Storage for both the video and the elicitation interview must be planned ahead of time, with appropriate human subject review board approval. Transcriptions of the video and the audio must be completed, so that the researcher can connect the two together. The analysis of the data needs to include the integration of the video data with the audio interview data, for instance placing the data into a single document to better see their connections. This typically requires using a theory-driven approach to coding the data. The end product of this analysis will help researchers better infer participant ideas and experiences of the phenomena begin studied (Otero & Harlow, 2009). These steps were followed in conducting the qualitative phase of this dissertation, in the planning of the research questions, the construction of the interview protocols, and in the results found through analyzing the interview data, as found in Chapter 4.

Video elicitation interview protocols. The video elicitation interview protocols were developed from a protocol used during a previous pilot study I conducted regarding student experiences with IVVs. From these original protocols, I updated these protocols to include questions more specific to each IVV (See appendices B and C). To do this, I watched both the Newton's Second and Newton's Third Law IVVs multiple times to be sure each interview protocol worded questions pertaining to the content of IVV as well as word questions in ways that were more understandable to the participants. During each interview, field notes were taken on each protocol to help with the analysis for each interview.

Data Analysis

Data analysis for this dissertation was iterative in that initial participant-level data was analyzed immediately before conducting each video elicitation interview. After all data was collected for each participant, the qualitative analysis for each participant was performed. After the qualitative analysis was complete, the conceptual profiles were created. Finally, common themes across all participants and their experiences were explored.

Quantitative Analysis

Pre-test and post-test scores were collected for every student participant in this study. Hake's gain was calculated (Hake, 1998) for Newton's Second Law and Newton's Third Law questions separately. Hake's gain is an oft-used tool for conducting pre-post analysis in physics education (Beichner, 2009). Data was used for each participant's pre- and post-test scores. Hake's gain is calculated as follows: (Post%-Pre%) / (100%-Pre%). Hake found that courses taught in an interactive manner can expect a gain of around 0.48, while courses taught in a more traditional way can expect a gain of around 0.23. In this dissertation, Hake's gain was calculated using Microsoft Excel. Hake (1998) also classifies the meaning of gain. Low gain is any gain less than 0.3. Medium gain is greater than or equal to 0.3 but less than 0.7. High gain is greater than or equal to 0.7. Initial results from the LivePhoto Physics Group's research at the University of Cincinnati (Koenig, personal communication) found low gain (g=0.17) for students that participated in a class that used IVVs. This score was calculated from the FCI questions in my instrument along with the two questions written by the LivePhoto Physics Group pertaining to Newton's Second Law. In contrast, for Newton's Third Law, they found much different gains. Calculating Hake's gain from the same questions used in my instrument, they found a medium gain (0.39) for students that participated in a class that used IVVs. From my data, I calculated Hake's gain for each of the following: each individual, each question, the questions used in my instrument that are in common with the LivePhoto Physics Group, the entire instrument, and finally, for physics versus non-physics students. See Chapter 4 for discussion regarding these gain scores.

Qualitative Analysis

Qualitative interview data was used to answer the qualitative research questions, paying close attention to how the data described the student experiences with IVVs, how student conceptions changed as a result of completing IVVs, and how students experienced *elicit*, *confront*, *resolve,* and *reflect* while completing IVVs. The audio recording of the video elicitation interview captured any question and answer dialogue between the researcher and the student. Each audio and transcript file was named similarly, using a pseudonym chosen by the student. For instance, the first student chose the pseudonym "Ariel." The files for this student were named "N2 Ariel Video Elicitation Interview" and "N2 Ariel Video Elicitation Interview

Transcript." All subsequent files for Ariel included this pseudonym as well as the N2 label. These files were saved on a password-protected computer for the duration of this project. I transcribed each interview transcribed verbatim as soon as possible after each interview. I chose to do these transcriptions myself in order to become intimately familiar with my data as well as increase the validity of my findings. During the transcription process, I memo-ed initial thoughts about the data as possible findings began to arise. After each transcript was complete, a final read through while listening to the audio recording took place to ensure accuracy of each transcript.

As each transcript was completed, the transcript was placed in MAXQDA for qualitative analysis. Initial coding took place using this software. Initial codes included instances of *eliciting*, *confronting*, *resolving*, and *reflecting*. Since these four items are of such importance for the student experience of each IVV, I coded instances where students experienced any of these. Through open coding, other codes were then added as student actions with the IVVs diverge from these initial actions. Examples of these codes include *no resolve/reflection*, where instances of *confront* were not *resolved*, or *through IVV* and *through interview* to distinguish between where a *reflection* occurred. As new codes were created, I went back to earlier transcripts to recode them for these new codes. This process is referred to as the iterative or inductive approach (Bradley, Curry, & Devers, 2007; Creswell, 2012). After all transcripts were thoroughly coded, I used the constant comparative method of qualitative data analysis (Strauss, 1987) to group codes by theme around the initial four codes. In other words, any codes that specify student actions centered around *eliciting* were grouped under *eliciting*. One of the goals of this qualitative analysis was to determine the different student experiences with the IVVs. This type of analysis is a hallmark of a phenomenography (Marton, 1994). As qualitative research is emergent, there were some codes that described student actions or behavior outside the realm of the four initial codes, such as *no resolve/reflection*. These codes helped lead me to richer understandings of the experience participants had with each IVV.

The interview data from Newton's Third Law was analyzed first. After completing the first analysis of the N3 data and the 15 participants' experiences with the N3 IVV (N3 will be used as shorthand for Newton's Third Law), I had coded a total of 575 (686)[2] items. I started from the ECRR framework and quickly began adding new codes. Under *elicit*, I found two distinct instances where the IVV *elicited* information from the participant. The IVV either *elicited* correct information or incorrect information. During the first go-around of the analysis, I found 67 (68) instances of information being *elicited* by the IVV. Of these, 36 (36) of these elicitations *elicited incorrect* information of the participant while 30 (31) of them *elicited* correct information. Fifty-five (66) times, the IVV *confronted* a misconception or an incorrect conception of Newton's Third Law and collisions. There were 83 (86) instances where the *confrontations* were *resolved*. Finally, I found 76 (102) moments of *reflection*. Originally, I did not distinguish between each *reflection*. However, I quickly realized that some of these instances occurred as a result of the IVV and some of them occurred as a result of the participation with the video elicitation interview itself. During the second full analysis, I went back through all the interviews and verified that I have found all instances of each code as well as further coded each *elicit* as *correct* or *incorrect* and each *reflection* as *through interview* or *through IVV*.

One major code I did not initially have that I realized early on that I needed to have is that of *misconception*. Three major misconceptions have been found in both the quantitative and qualitative data for Newton's Third Law: (1) greater mass implies greater force, (2) speed and

[2] Numbers in parentheses denote the number of codes after the second full analysis, while the numbers in front of parentheses denote the number of codes found during the initial analysis.

force (acceleration) are equivalent, and (3) active agent produces the greater force. I initially found 41 (51) instances where I found a misconception. Sixteen (18) of these were the greater mass implies greater force misconception, 8 (9) were the speed and force are equivalent misconception, and 15 (20) of them were the active agent misconception. At this point in the analysis, I realized that I needed to be able to then connect these misconceptions found within the qualitative analysis to those found from the quantitative analysis as part of the construction of conceptual profiles. Since I was trying to determine each participant's conceptual profile, I needed to be able to compare the quantitative and qualitative data. So not only did I then code *incorrect elicitations* as pre-misconceptions, but also found all instances where a misconception occurred in every interview.

Four other new codes were created along the way in this initial coding process: *limitation*, *effectiveness*, *sense-making*, and *compare N2 and N3*. I found 16 (20) instances where the IVV was limited, such as with its effectiveness of this IVV to counter the active agent misconception. I also found 32 (47) instances where a participant referred to the IVV as being effective at teaching them about Newton's Third Law. Eleven (15) times I found instances where the participant explicitly made sense of the learning. Finally, with six participants volunteering to complete both the N2 and N3 IVVs, I had the ability to ask these participants to compare the two IVVs. At this point, I found 15 (17) specific instances where those six participants actively compared the two IVVs.

In analyzing the Newton's Second Law interviews, I followed a very similar process. A new code that was not found in analyzing the Newton's Third Law data that was found quickly in the Newton's Second Law data was *no resolve/reflect*. After this code was discovered early on in the Newton's Second Law data, I went back through earlier transcripts to find every instance where the N2 IVV *elicited* incorrect information of a participant but did not *resolve* that conflict (N2 will be used as shorthand for Newton's Second Law.). Also, new misconceptions were added as codes for the Newton's Second Law. Chapter 4 goes into depth regarding these analyses.

Three specific validity strategies (Creswell & Miller, 2000) were employed to ensure the soundness of the qualitative strand of this study. The first strategy was peer debriefing. In this validity strategy, I partnered with a colleague to review the coding scheme I used with the data set. This peer was a sounding board to ensure that my codes matched what was seen in the data as well as offered feedback on the depth of these codes. Peer debriefing was used at the end of the qualitative analysis. The second validity strategy was that of triangulation, a process where a researcher combines multiple data sources to establish themes in the research. In my case, I combined the interview data for all students in order to add credence to themes that emerged for each IVV in order to paint a picture that may be different for each IVV. The final validity strategy was that of member checking. Since a phenomenography is designed to describe the different and limited number of ways a phenomenon is experienced, I asked one participant to read my conceptual profile of her experiences with both the N2 and N3 IVVs. Upon reading these documents, Evelyn Applegate suggested that they accurately *reflected* her thoughts and experiences with both IVVs. By checking with this participant, I was able to conclude that the processes I used in constructing these profiles were likely good.

Mixed Methods Procedures

The mixed methods procedures described in this section were the means by which many of the results of this dissertation were found. Most findings came out of the conceptual profiles for the participants followed by comparisons between and among these profiles. These comparisons existed between both individuals within groups, such as all individuals that completed the Newton's Second Law IVV, as well as comparisons between groups, such as physics students versus non-physics students that completed Newton's Third Law.

Individual Level Analysis—Constructing Conceptual Profiles

One of the most important data analysis tools created in this dissertation was that of the construction of conceptual profiles. Put simply, in this dissertation, a conceptual profile was a mixed methods tool that described a participant's conceptions regarding a given topic and tracked those conceptions as each participant learned as a result of completing the IVV. These profiles were necessarily mixed in nature in that they contained data and analyses from both the quantitative and qualitative strands of data analysis. Constructing each profile was a lengthy process that included multiple data tables and finished with a written description of each participant's conceptions and how they changed or did not change over time.

The first component of the conceptual profile came from the answers to the quantitative instrument. Using the literature on misconceptions in Newton's Laws, I coded each wrong answer from the instrument to describe the misconception that each wrong answer measured (See appendices J and K). I created an Excel spreadsheet that identified the misconceptions for each question. This spreadsheet was set up to type in each answer for both the pre-test and the post-test. Once answers were entered, the misconception for each wrong answer was listed next to the wrong answer. Correct answers were quickly counted and Hake's gain was calculated, taking roughly one minute to complete just prior to the video elicitation interview. In doing so, I was able to use the results from the quantitative data to inform some of the questions for the video elicitation interview. In other words, knowing a participant had multiple instances in both the pre- and post-test where they exhibited the *greater mass implies greater force* misconception allowed me to probe them for their thinking regarding those questions to help solidify my understanding of their thinking regarding that misconception.

For the questions that came from the FCI, identifying misconceptions for wrong answers was straightforward, as Hestenes, Wells, and Swackhamer (1992) included the misconceptions each answer measured in their original article containing the FCI. The questions written by the LivePhoto Physics Group were likewise as straightforward, as these questions mirrored the style of the FCI. The challenging questions to code were those from the FMCE, mostly due to the structure of the answers on this instrument. For instance, questions 4-11 on my instrument all came from the FMCE. These questions were each statements describing the motion of a car and the student was to match each statement with a force versus time graph that best describes the statement. One of the possible answers was *J*, or “None of these graphs is correct.” This answer did not have an associated misconception describing it, since the answer itself did not give enough information to accurately identify the misconception the student has for why they answered *J*. Another issue found with these questions was that the Newton’s Second Law IVV had participants graph velocity versus time, not acceleration versus time. This meant that they might have been led to answer *C*, a graph that had a positive slope and was linear. Put another way, students, without knowing it, confused velocity and acceleration (or force), which was a misconception, but again, knowing whether they were actually exhibiting this misconception was difficult to attain from their answers on the instrument. The portion of the instrument measuring concepts from Newton’s Third Law also had similar issues. In questions 17-21, students could answer *J*, or “None of the answers above describes the situation correctly” or they could have answered *C*, or “Neither exerts a force on the other, the car gets smashed simply because it is in the way of the truck.” In both of these cases, there was not a misconception found in the literature that described either of these answers. Thus, in the tool created to identify misconceptions from the quantitative instrument, these answers were left un-coded.

For each participant, the data analysis tool was used during the data collection process. Space was created in this tool to allow for note-taking on my part during or immediately following the interview. After completing the coding of all the interviews for each IVV, I came back to these tools as I created more spreadsheets as part of the conceptual profile. In this mixed analysis, I ended up creating five more spreadsheets followed by a 3-6 page description of each participant's conceptions and how they changed over time.

The first spreadsheet simplified the quantitative data into a much smaller table. These tables tabulated the number of instances of each misconception that was held before and after completing the IVV, along with the number and percent correct before and after. These results were broken down by full instrument as well as questions in common with the LivePhoto Physics Group. Finally, a column was created to show Hake's gain for the full instrument as well as the LivePhoto Physics Group questions. The next spreadsheet created a table of misconceptions identified from the interview. This coded data came from MAXQDA and was listed as a misconception if the participant held it after completing the IVV. The third spreadsheet identified all instances of the ECRR framework for each participant. This spreadsheet was useful in showing how each participant did or did not experience the sequence of ECRR. The fourth spreadsheet was the first joint display, a table that mixed quantitative and qualitative data (Plano Clark & Sanders, 2015). This table combined the three previous tables into a single spreadsheet to look for patterns, such as if they experienced the ECRR framework and comparing that with their gain score. Finally, a spreadsheet was created to put in a small table both the quantitative and qualitative data, my interpretations of the data, and then combine the two to describe the effectiveness of that IVV in terms of changing that participant's conceptions of the concept being taught by the IVV. This method of integration is referred to as joint displays (Plano Clark & Sanders, 2015). Visual displays of mixed data, especially in concurrent mixed methods studies, can be quite useful in giving inferences more clarity. In addition, a joint display has the power to show how the data converge to form results and conclusions. All five of these spreadsheets were then used to write each participant's conceptual profile, put words to the data from the spreadsheets and included pertinent quotes from the interviews to show instances of student experiences with ECRR and where their misconceptions were found during their pre-test, post-test, and interview.

In creating each participant's conceptual profile, I not only integrated the data to do so, I ended up analyzing both data sets for each participant simultaneously. This process accurately describes the analysis required of a fully integrated mixed methods design, where the data sets interact with each other and inform later data analysis (Teddlie & Tashakkori, 2009). In my case, I created conceptual profiles for all participants of the Newton's Third Law IVV before creating conceptual profiles for all participants of the Newton's Second Law IVV. By analyzing data in this order, I was better able to allow earlier conceptual profiles of N3 participants to inform conceptual profiles of other N3 participants. For instance, if an early participant had a certain experience at a specific time within the IVV, I was able to look at the experience of the next participant at the same juncture of the IVV to help determine whether the experience was the same or different. This then assisted with conducting the phenomenography, where I was interested in describing all the different experiences participants had.

IVV-Level Analysis—Identifying Levels of Effectiveness

One of the conclusions reached during the analysis of each participant's conceptual profile was the effectiveness of an IVV at changing that student's conceptions regarding either Newton's Second or Third Laws. Three main levels were determined: effective, partially effective, and not effective. Determining levels of effectiveness required both the quantitative and qualitative data to support the conclusion. In order for an IVV to be effective at changing a participant's conceptions regarding either Newton's Second or Newton's Third Law, Hake's gain from the quantitative instrument needed to be medium or high, and the qualitative data needed to support the change of that participant's conceptions. A partially effective level occurred when there was evidence to support a change in a participant's conceptions from either Hake's gain or the qualitative data for that individual, but not both. Finally, a not effective level occurred when there was no Hake's gain from the quantitative data and lack of a clear change in conceptions from the qualitative data.

Group-Level Analysis—Examining for Group Differences

Multiple group level analyses were conducted. These included comparing how physics versus non-physics students experienced each IVV, how participants that completed each IVV compared their experiences, how participants experienced each question within each IVV, and the differences in results on the quantitative instrument compared to work already conducted by the LivePhoto Physics Group.

Phenomenography

Since the main goal of a phenomenography is to describe the different ways a group of participants experienced a given phenomenon, the mixed data was compared, specifically the conceptual profiles, to determine each unique experience. These experiences then helped to explain the various levels of effectiveness of an IVV at changing student conceptions regarding Newton's Second and Third Laws as well as experiences of the ECRR framework within the completion of that IVV.

Validity Approaches

This dissertation faced two main validity threats. The first threat was that of the elicitation interview having undue effect on whether a student changes his or her conception or not. Creswell and Plano Clark (2011) refer to this as a data collection bias. To minimize this threat, they suggest that separate data collection procedures be used. The way my study was designed, I was unable to remove this bias directly. Since the data needed to be collected in a specific order, I had to examine the qualitative interview data carefully to code for whether a change in a conception was as a result of the IVV or the VEI. This process was challenging and may have revealed certain biases. Another means by which I was able to determine if my data had bias was to compare my effect size (Hake's gain) to the effect size the LivePhoto Physics Group has already found for each of the IVVs. These differences are discussed in chapter 4.

The second validity threat that needed attention came in the form of preventing one portion of the data from receiving more weight than the other. To prevent this from occurring, I created multiple joint displays that combined both the quantitative and qualitative results together. Not only that, but any conclusion made regarding the effectiveness of an IVV at changing a participant's conceptions needed to be made by combining both data types. By doing so, this also helped enhance my inferences.

Meta-Inferences

According to Tashakkori and Teddlie (2008), an inference is "the process of interpreting the findings AND the outcome of this interpretation to provide answers to the original research question" (p.103). Further, they suggest that inferences are how all the data and research questions relate to each other. As applied to my study, in order to make strong meta-inferences, I first needed to ensure that the quantitative and qualitative strands yielded strong inferences (Teddlie & Tashakkori, 2009). Also, strong meta-inferences required that I answer my mixed methods research question and connect back to the purpose and rationale of the study itself. I used Teddlie and Tashakkori's (2009) process of evaluation for inference quality diagram (Figure 12.5, p. 307) along with their integrative framework for inference quality (Table 12.5, pp. 301-302) to judge the quality of the inferences for my dissertation. I make the argument that the design quality outlined in this chapter meets Teddlie and Tashakkori's research criterions 1-4 (Design suitability, Design fidelity, Within-design consistency, & Analytic adequacy). I further argue that the analysis methods outlined in this chapter meet Teddlie and Tashakkori's research criterions 5-8 (Interpretive consistency, Theoretical consistency, Interpretive agreement, & Interpretive distinctiveness) and 10 (Interpretive correspondence). I argue that the integration techniques outlined in this chapter meet Teddlie and Tashakkori's research criterion 9 (Integrative efficacy). In designing and implementing my dissertation in this way, I was able to make strong meta-inferences regarding the characteristics of the Newton's Second Law IVV and Newton's Third Law IVV that affect student conceptions.

Ethical Issues

During this dissertation, I ensured strong ethics were applied according to standards in the field (Creswell, Klassen, Plano Clark, & Smith, 2011; Hesse-Biber, 2010). All data collection tools as well as consent forms and recruitment scripts were approved by the Institutional Review Board of Kettering Medical Center prior to their use in this dissertation. The University of Cincinnati Institutional Review Board then approved this approval. Participant identification was anonymous. Student participants were informed of the multiple forms of data to be collected prior to the start of their participation. Burden to provide information was minimized wherever possible by only asking necessary questions. Since students were asked to give up about 45-60 minutes of their time, they were offered a $10 gift card to Starbucks, Chipotle, or Panera as a means to compensate them for their time. Interview questions asked of each student were not personal in nature. Rather, interview questions concentrated on how each student interacted with the IVV, and thus, each participant faced minimal risk. In addition to very little risk, the participants in this study had the possibility of increasing their knowledge of physics - a direct benefit to their participation. Finally, results of this study will help inform the LivePhoto Physics Group as they continue to create new and edit old IVVs for the benefit of other and future students.

Summary

In this chapter, I have described the research methods used to conduct the research. A fully integrated mixed methods design was used to answer the research questions. A convenience sample of 22 total participants was recruited. The quantitative instrument and qualitative data collection methods were outlined. The methods of analysis of both the quantitative and qualitative data was described. These methods culminated in the creation of conceptual profiles for each participant and it is these profiles that were then used to make comparisons between participants as well as to draw conclusions on the effectiveness of an IVV's ability to change conceptions regarding either Newton's Second or Third Law.

Chapter 4

Introduction

As stated in Chapter 1, this study set out to understand what prompted student to change or not change their incorrect conceptions of Newton's Second or Third Laws in response to an intervention designed to overcome them. This chapter presents key findings in four distinct areas: Newton's Second Law IVV findings, Newton's Third Law IVV findings, physics versus non-physics students' findings, and findings from participants that completed both IVVs. As part of the process of conducting a phenomenography, throughout each section I categorized participant experiences with the IVVs and the levels of effectiveness for each IVV. These categories of experience include how each participant experienced the ECRR framework and the impact these experiences had on their conceptual change. To accomplish this, I present both quantitative results and qualitative results together to reach conclusions regarding both the experiences and the effectiveness.

Demographic Description of Participants

Table 4.1 lists the 21 participants who completed this study, which ones were physics students at the time of their participation, and which IVVs they completed. In total, nine of the 21 participants were students currently taking a college physics course, while 12 were not. Five of the nine physics students volunteered to complete both IVVs, while two of the twelve non-physics students completed both IVVs. Each student chose their own pseudonym and some included both a first and last name in their choice. These last names are useful in multiple cases as some participants chose the same first name.

Table 4.1

Participant Demographics

Participant	Physics Student	IVVs Completed
Eloise	Yes	N2, N3
Evelyn Fierce	Yes	N2, N3
Randy Osborne	Yes	N2
Freddy Fazbear	Yes	N2, N3
Clarissa Beckham	Yes	N2, N3
Marie Skaggs	Yes	N2, N3
El Rato	Yes	N3
Marie	Yes	N3
Renee Mendenhall	Yes	N3
Renee	No	N2
Lily	No	N2
Peggy Carter	No	N2, N3
Sally	No	N2
Evelyn Applegate	No	N2, N3
Demi Lovato	No	N2
Peyton Smith	No	N2
Ariel	No	N3
Mia	No	N3
Shannon	No	N3
Rosa	No	N3
Kristen	No	N3

Key Findings

Participants in this study experienced components of the ECRR framework through completion of either or both the N2 and N3 IVVs. The components of the ECRR framework were experienced differently for each IVV and had a different impact on the change of misconceptions these participants held at the start of this research. The N3 IVV enacted the ECRR framework in a more sequential manor than did the N2 IVV and this led to the N3 IVV having a greater effect on changing misconceptions than the N2 IVV, while the N2 IVV still had a positive impact. Finally, students that completed both IVVs preferred the N3 IVV to the N2 IVV in terms of helping them learn. The rest of this chapter reports findings from participants of the Newton's Second Law IVV followed by findings from participants of the Newton's Third Law IVV, how physics and non-physics students experienced each IVV, and how these findings support these statements.

Newton's Second Law IVV Findings

In this section, I summarize the various segments that make up the N2 IVV. Following that, I explain where I expected the ECRR framework to be found in the IVV. Next, data from multiple locations within the IVV is used to show participant experiences with the ECRR framework. The levels of effectiveness in terms of changing student conceptions come next. The section finishes by comparing how physics and non-physics students experienced the N2 IVV.

Summary of N2 IVV

Before delving into the Newton's Second Law data, it is helpful to summarize the videos and interactions that can be found within the Newton's Second Law IVV. During the first video segment of the N2 IVV, onlookers in the video are told they are about to watch a cart with a person on it accelerate via a compressed-gas canister. The person on the cart interviews two onlookers within the video to predict the motion of the cart. After watching the cart accelerate, the onlookers are then asked to describe the motion. Next, the interviewer removes himself from the cart and asks the two students to predict the motion a second time, after which they watch the cart accelerate a second time but without a rider. This video sequence takes about four and a half minutes.

After the first video segment, participants go to the next page within the IVV to answer the first multiple-choice question (see Figure 4.1). Included on this screen are two videos. The video in the upper left quadrant of the screen explains that a participant should answer the question and can use the video in the upper right, which repeats the accelerating cart from the previous page. It is at this point in the N2 IVV where student ideas can be *elicited* for the first time.

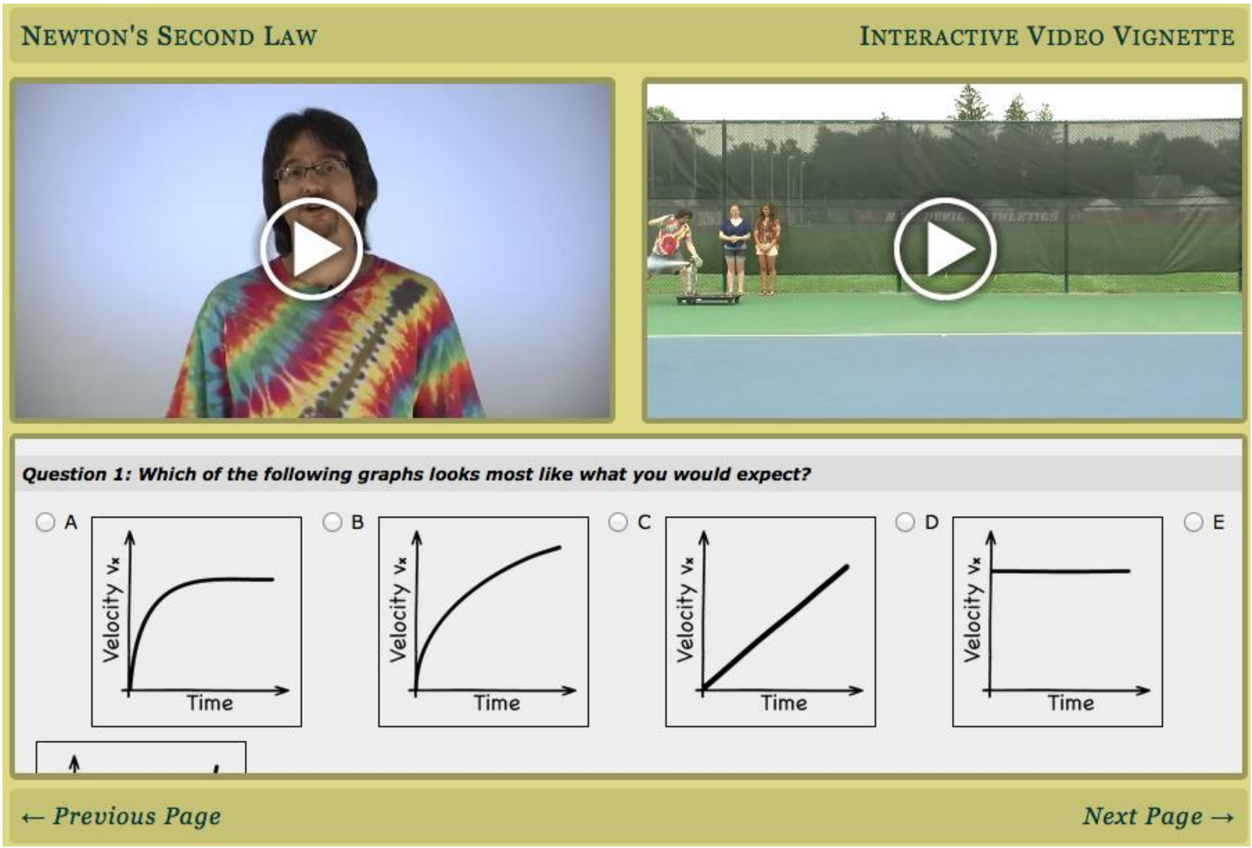

Figure 4.1. N2 IVV Question 1. 2 of 13 (15%) Students Answered Correctly with *c*.[3]

The third page in the IVV has participants create a graph of velocity versus time by clicking on the moving cart (see Figure 4.2). This graph ends up linear and matches choice C from the previous multiple-choice question. This page gave participants an opportunity to experience *confront*, *resolve*, and *reflect* based on their thinking about the graph they created and its relation to their answer from the multiple-choice question.

3 All screenshots for the two IVVs can be found through the following website: http://www.compadre.org/IVV/.

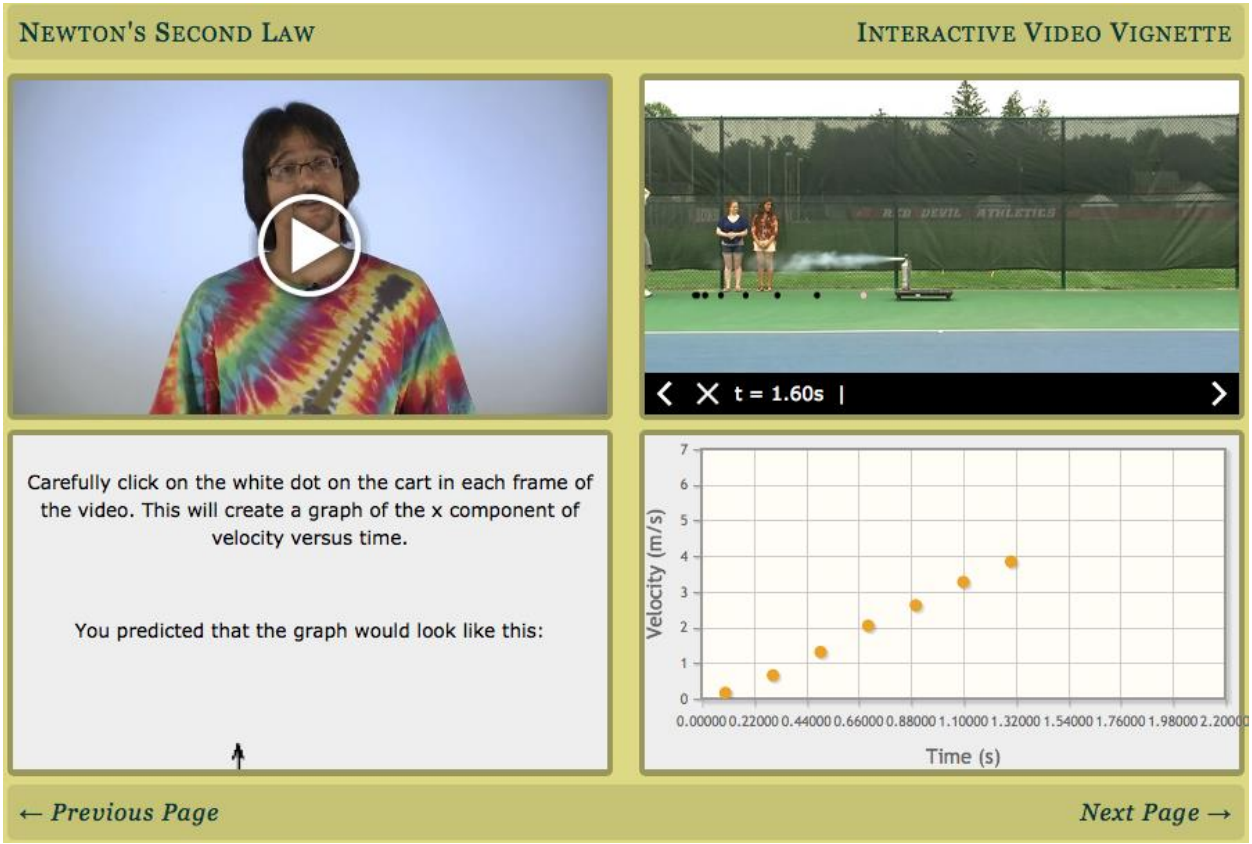

Figure 4.2. N2 IVV Graph 1.

The video that follows the first graph explains that the participant has now seen a precursor to Newton's Second Law, but that to really understand Newton's Second Law, data will need to be collected from the lab to take more careful measurements. Similar to the previous graph, participants are to click on the cart to create a velocity versus time graph (see Figure 4.3). This page is accompanied by a video explaining how to complete the graph.

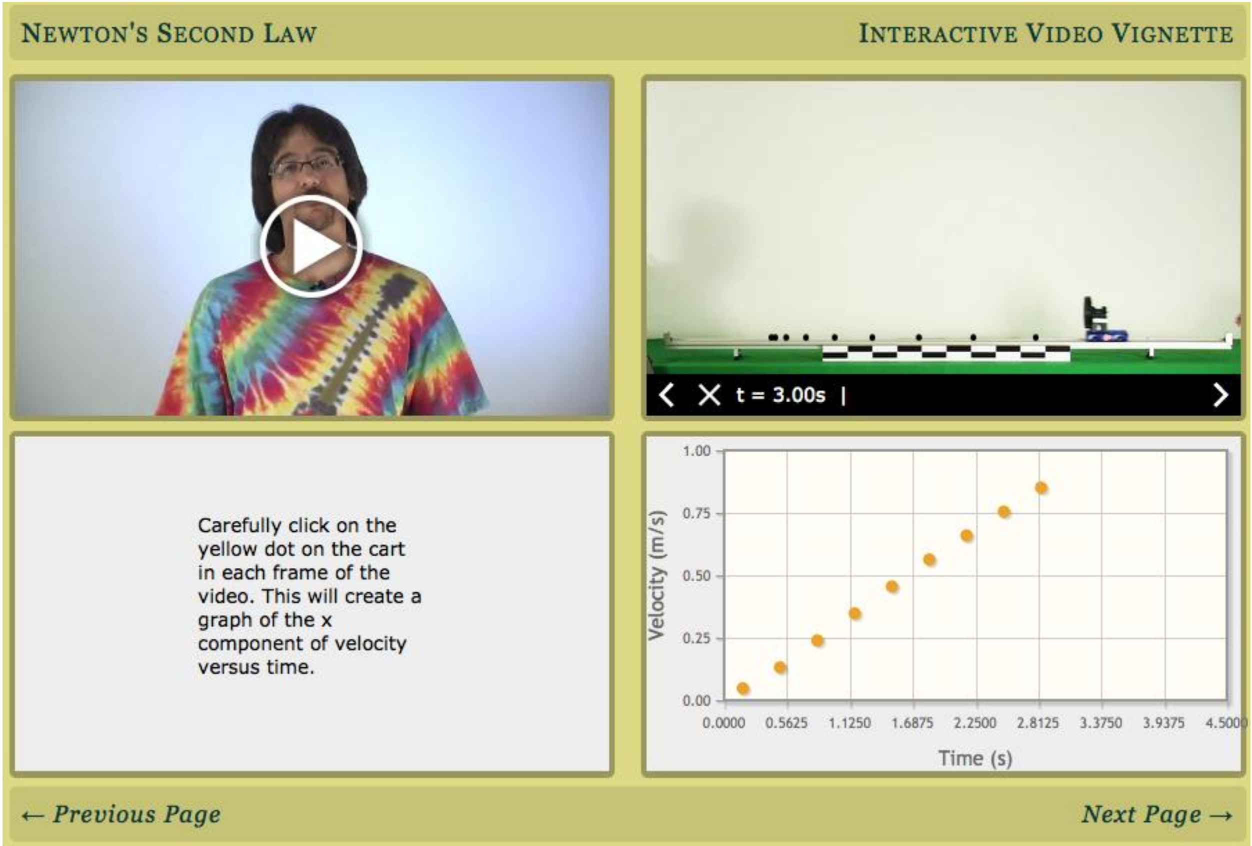

Figure 4.3. N2 IVV Graph 2.

The next page in the IVV contains the second multiple-choice question and second place within the IVV where student conceptions can be *elicited*. In this question, participants are asked what the acceleration would be if the force of the fan stayed the same but the mass on the cart doubled (see Figure 4.4). After this page, participants create a velocity versus time graph for this situation. It is in this following page where participants had the opportunity to experience *confront* if their answer to the previous question was incorrect, *resolve* the conflict if it existed, and *reflect* regardless of their multiple-choice answer.

The next page in the IVV has participants create lines for each of the two previous graphs. In these lines, the slopes are shown in the bottom right hand corner. The page also asks whether the prediction from Question 2 was correct (see Figure 4.5). The video in this page explains how to create the lines and also asks the participant to compare the two slopes. The slopes of each graph is in the lower right quadrant of each graph.

Figure 4.4. N2 IVV Question 2. 11 of 13 (85%) of Students Answered Correctly (1/2 a).

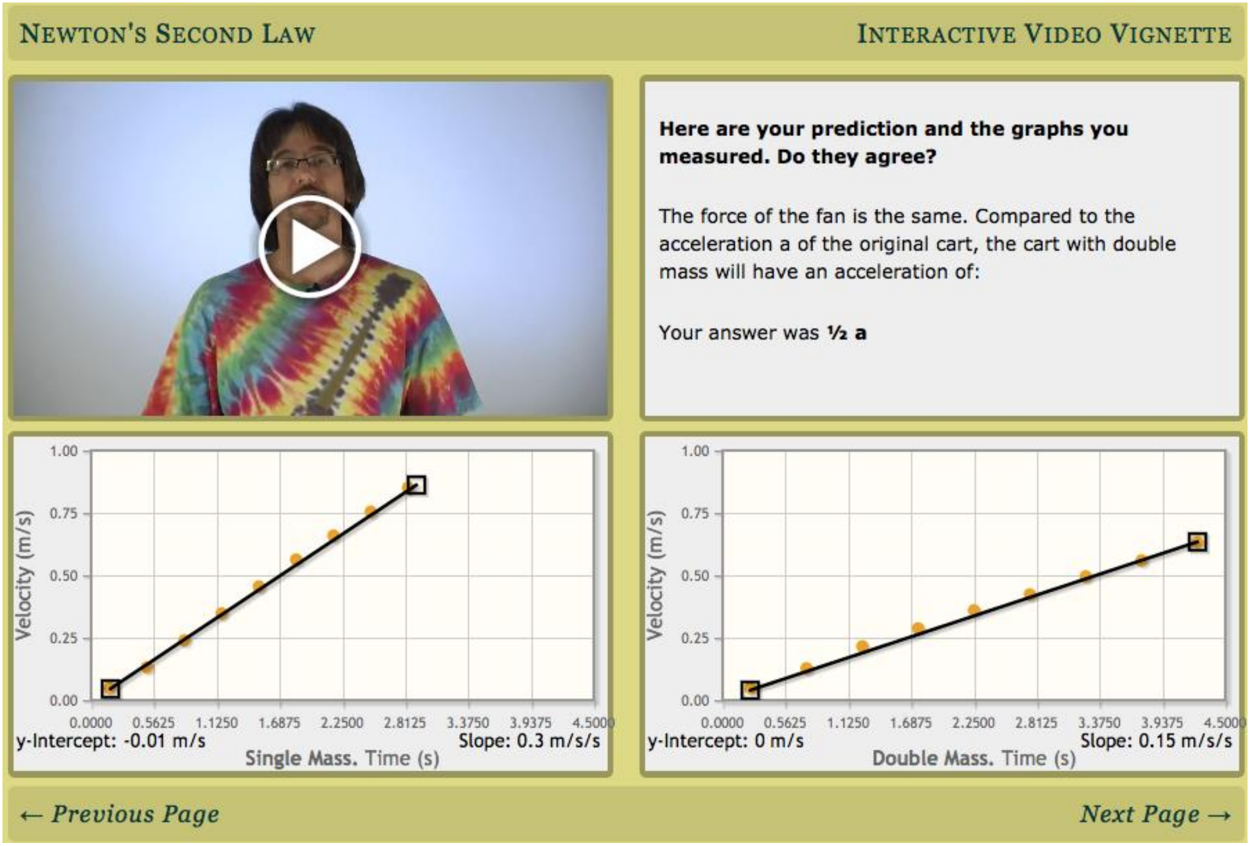

Figure 4.5. N2 IVV Slopes. This page offered opportunities to experience *reflection*.

The final video in the IVV includes the narrator summarizing the IVV by explaining that the net force is proportional to mass times acceleration. The narrator in the video goes on to say that the net force is equal to mass times acceleration, which is Newton's Second Law.

Where ECRR Can be Found in the N2 IVV

During the N2 IVV, there are points where a participant has several opportunities to experience portions or the complete sequence of the ECRR framework. The first key point within the N2 IVV where the ECRR framework could be experienced occurred when the IVV asked the participant to select the graph of velocity versus time for the video they just watched (see Figure 4.1). This question offered an opportunity for a student conception to be *elicited*. If this question was answered incorrectly, the participant had the opportunity to experience *confront, resolve,* and *reflect*, depending on their thinking about the graphs as expressed during the VEI. The second key point occurred when the IVV asked the participant to predict the acceleration when the mass was doubled and the force remained the same (see Figure 4.4). Again, this question offered an opportunity for a student conception to be *elicited*, and like at Question 1, offered an opportunity to then experience *confront*, *resolve*, and *reflect*. On the other hand, since the graphs participants created could not be created incorrectly, these graphs in the IVV could not *elicit incorrect* from participants. How participants experienced the ECRR framework at Questions 1 and 2 as well as within the N2 IVV helps explain differences found in quantitative scores on the post-tests.

Levels of ECRR Experiences

From the analysis of the quantitative and qualitative data, two levels emerged to categorize and describe the extent of students' experiences with the ECRR framework in the context of completing the N2 IVV: full experience and partial experience. A full experience occurred when the ECRR framework was experienced during the IVV and a partial experience occurred when any portion of the framework was missing from the experience. There were also two ways in which the ECRR framework could be experienced: 1) in sequence starting at a given point within the IVV, typically beginning at Question 1 or Question 2 and finishing shortly thereafter or 2) across the entirety of the IVV.

As mentioned earlier, there were two major points where the N2 participants experienced sequences of the ECRR framework: Question 1 and Question 2. These two questions were the main ways in which the N2 IVV was able to *elicit* student conceptions. The 13 N2 participants experienced the sequence of the ECRR framework in different ways beginning at these two major points within the IVV (see Table 4.2). Based on the VEIs, only four of the 13 participants experienced the full ECRR sequence beginning at Question 1: Randy Osborne, Freddy Fazbear, Evelyn Applegate, and Marie Skaggs. In Table 4.2, these sequences and participants are in bold. Both Peyton Smith and Lily experienced all but *reflect* at this point in the IVV. Peggy Carter and Demi Lovato both answered Question 1 correctly, and then *reflected*. The remaining participants experienced an *elicit incorrect*, but did not experience both a *confront* and a *resolve* immediately following, while most did end up *reflecting*, either during the IVV or the VEI.

Table 4.2

N2 Participant ECRR Sequences.

Participant	N2 Q1	N2 Q2	LPPG Hake's Gain
Renee	Elicit Incorrect, both Resolve and Reflect in VEI	Reflect in IVV and VEI	0.33
Eloise	Elicit Incorrect, Reflect in VEI	Reflect in IVV	0.33
Lily	ECR	Reflect in IVV and VEI	0.33
Evelyn Fierce	Elicit Incorrect, Reflect in VEI	Reflect in IVV and VEI	0
Peggy Carter	Reflect in IVV	CR, Reflect in IVV and VEI	0.5
Randy Osborne	**ECRR**	Resolve, Reflect in IVV	1
Sally	Elicit Incorrect, Confront, Reflect in IVV	Reflect in IVV	0.33
Freddy Fazbear	**ECRR**	Reflect in IVV	0.67
Clarissa Beckham	Elicit Incorrect, Reflect in IVV	Reflect in IVV	0
Evelyn Applegate	**ECRR**	Reflect in IVV	1
Demi Lovato	Reflect IVV	**ECRR**	**0**
Marie Skaggs	**ECRR**	Reflect in IVV	0
Peyton Smith	ECR	ECR, Reflect in VEI	0.67

Question 1 ECRR experiences. At question 1, participants either experienced the full ECRR sequence or a partial sequence. Evelyn Applegate experienced all four components of the ECRR framework, especially *reflect*.

> 06:59 Interviewer: So, interpret the graph that you've chosen, graph "e". (*elicit incorrect*)
>
> 07:02 Evelyn Applegate: I, well, when I watched the video, I kind of thought about him being on it (*reflect*). And now I know I was wrong (*confront*), but I thought it would like, I thought it kind of took off slower and then it sped up, but it sped up at a constant (*resolve*).

This passage showed Evelyn's experience with the components of the ECRR framework. The IVV *elicited* an incorrect conception from her and she quickly realized why it was incorrect as well as *resolved* the conflict in a timely fashion. Based on her participation with the N3 IVV previous to this point (she completed the N3 IVV prior to the N2 IVV), much of this quick change in her thinking was due to her natural predilection to *reflection*. The *reflecting* continued into when she was actually creating the graph herself.

> 09:42 Evelyn Applegate: And I was like, I should have went with graph "c", because that was, I don't know why my initial instinct was "e", but I contemplated "c". Um, I guess I just thought when I started clicking on it, it made sense that it should have been constant accelerating, positive slope.

In *reflecting* in this way, Evelyn showed that the N2 IVV clearly caused her to think about what she was doing as well as make connections to previous learning from the IVV, both components of *reflecting*.

Sally experienced three components of the ECRR framework, though she did not experience a *resolve*. This incomplete experience of the framework ended up impacting her learning.

07:04 Interviewer: All right, so explain, uh, your thinking behind answer “e” here.

07:10 Sally: ‘cause I knew it was speeding up and, I don’t know, it kept increasing so it couldn’t have been the constant one.

07:19 Interviewer: Which was the constant one?

07:21 Sally: I mean, it would like, it increased at first, but then it was constant, but I thought it kept increasing until the rope stopped it.

08:49 Interviewer: So, compare your graphs for me.

08:55 Sally: Um, mine was kind of constant, the one that I picked was kind of constant at first, but it started increasing right off the bat.

09:48 Interviewer: What kind of comparison did the video ask you to do between the graph you chose [e] and the graph you just created?...Did it ask you to compare?

09:50 Sally: No.

In this lengthy passage, Sally showed she *reflected* while she completed the IVV, but she did not notice conflicts in what she was saying. She kept using the word constant to describe graphs, which by itself is not incorrect, but she was unable to describe what part of each graph was constant. The graph she chose, graph “e” was a curve, with no constant sections. The graph she created in subsequent portions of the IVV were increasing lines, with constant slope. For her, that lack of a *resolve* in this conflict through not requiring her to compare the two graphs prevented her from coming to a *resolve* in her thinking.

Clarissa did not experience all four components of the ECRR framework. The one main instance of *elicit incorrect* occurred at the same juncture within the IVV as many other participants.

> 07:50 Interviewer: Now it seemed like you were doing a lot of thinking when selecting graph “b”. What were your thoughts at this point? (*elicit incorrect*)
>
> 07:59 Clarissa Beckham: Um, I think I was looking at it as acceleration versus time, even though it says it was velocity over time. (*reflect*)
>
> 09:21 Interviewer: So, how do you know whether your prediction is correct?
>
> 09:37 Clarissa Beckham: So my prediction is wrong. (*confront*, though during the VEI)
>
> 09:39 Interviewer: Did you know then, looking between the two?
>
> 09:42 Clarissa Beckham: I don’t think so. (*no resolve/reflection*)

This is an interesting sequence during the VEI. Clarissa knew during the VEI that she was wrong, but the IVV did not require her to compare her incorrect graph with the correct one, and the conflict in her mind did not *resolve* itself. This may have been a contributing factor to her not changing her conceptions as measured by the quantitative instrument.

Renee’s experience at Question 1 was different than the previous three participants in that the IVV did not cause *confront* or *resolve* until she watched the IVV again during the VEI.

> 07:24 Renee: I picked it increasing and then going up constant rate, and I chose that because I think the first time watching it I feel as if it going at a constant rate, but now watching it again I feel like I saw it increase.

Later in the VEI, after continuing to watch, Renee went on to explain what the IVV did in response to the previous incorrect response.

08:33 Interviewer: So, we have here a picture of the graph that you chose in the previous question and then the graph that you made, uh, analyzing the video right there. What do you make of that?

08:43 Renee: Well, like I said in watching it the second time I definitely would have picked the second graph and not the graph I chose. I think that the graph that they show from the video, um, helps me to kind of analyze how the speed is going and increasing.

This passage illustrated how Renee experienced the N2 IVV. She felt that real *confrontation* and *resolve* in her thinking occurred only after watching the IVV a second time. She did not *reflect* on this process during the IVV, but rather after completing the IVV.

The N2 IVV *elicited* a number of incorrect answers from Eloise. For example, she had to choose what velocity-time graph described the motion in the videos.

08:56 Interviewer: So, uh, you answered on question 1, uh, the graph that you did, graph "a." Um, why did you select that answer? Or what made you think that was the right answer?

09:08 Eloise: Well I thought that it was the right answer because I thought that since it, like, took a little bit to gain some constant speed that it was going to have to like, it would start, but really, it didn't really gain constant, or like the speed remained, the acceleration was constant, because that's the slope of the line, but like the velocity increased, but I don't know why I thought, cause when I first thought that, I thought that took a little bit to get going, but really the entire time it remained constant.

This passage is fascinating for a number of reasons. Eloise was not able to adequately explain why she picked the answer she did. Graph "a" in this case showed the *force causes acceleration to terminal velocity* misconception, and in explaining why she picked it, Eloise showed she held the same misconception. She understood that the acceleration was the slope of the line. In spite of this and the fact that the acceleration was constant, she held onto the belief that the velocity would become constant after a time. It was not until the VEI where this misconception was actually *confronted*.

> 11:59 Eloise: Um, well the video like showed that it didn't, the velocity didn't like, didn't ever just stay at like, stayed constant, it actually just kept, like, accelerating.
>
> 12:13 Interviewer: there isn't a video that is talking about what the meaning of the graph from question 1a means or what words describe that graph?
>
> 12:39: Eloise: No.

At this juncture of the VEI, it was clear that the IVV *elicited* an incorrect answer from Eloise, but only showed what the right answer was, without mentioning her graph or trying to connect any of her correct reasoning to either.

This lack of *confrontation* and *resolve* within the IVV persisted further into the VEI when Eloise continued to look for the IVV to back up her conception, without actually allowing her conception to be dictated by what she sees. She really wanted her conception to be true.

> 14:22 Eloise: Well…if that's the force…probably acceleration's going to remain constant, because…Oh, no, the velocity is going to remain constant, 'cause the acceleration hasn't quite caused it, 'cause once acceleration…I'm contradicting myself. Um, well, because acceleration is remaining constant because as it, like gains, as the like as the velocity increases the acceleration is also…increasing? No…I'm pretty sure the velocity is increasing.

All of this *reflecting* Eloise showed here happened during the VEI, not during the IVV. There was conflict in Eloise's mind, but she was unable to adequately *resolve* this conflict during the IVV and even struggled to do so during the VEI.

Question 2 ECRR experiences. The experiences at the second key point within the N2 IVV were decidedly different. Only one participant experienced the full ECRR sequence: Demi Lovato. Eleven of the 13 participants answered this question correctly, that the acceleration would be ½ a, while only two participants experienced an *elicit incorrect*. Also, 12 of the 13 participants *reflected* while completing the IVV. These 12 participants connected back to the earlier video where they saw someone decrease the mass on a cart, keep the applied force the same, and resulted in an increased acceleration. The *reflecting* going on in the participants at this point within the IVV showed the learning that they were able to accomplish as a result of their participating in the IVV. This means that a majority of the N2 participants did learn correct physics, that when force remains constant and mass is doubled, the acceleration will be cut in half.

Within the N2 IVV, the participant experiences were drastically different at Question 2 than Question 1. Eleven of the 13 participants answered this question correctly. While many of the participants only *reflected* after answering this question, there were four additional unique experiences of the ECRR framework.

Randy Osborne answered Question 2 correctly, *reflected* about earlier videos he watched, but did not compare the slopes of the two lines (see Figure 4.5).

> 14:04 Randy Osborne: I chose ½ a based off what had happened earlier in the video when he was actually on the cart and had done that it was about, it looked like about half the speed of earlier when, then when he got up off of that, so I just kind of took that idea and

thought about it in reverse, that it would have to decrease in overall acceleration since he was adding weight to it this time.

The connection Randy made to an earlier video was striking. In the earlier video, when mass decreased, the acceleration increased. Randy took this idea in reverse to explain that if mass increased then the acceleration would decrease. This shows that Randy had a basic knowledge of the relationship between mass and acceleration when force is constant. However, he did not notice that he could have used the video to see if he was correct.

16:33 Interviewer: So, what were the accelerations in both cases?

16:48 Randy Osborne: Are they actually on the bottom of the graph down here?...Oh…I see the slope, yeah.

While Randy offered a correct explanation of why the acceleration would be half, while completing the IVV, he did not notice that the slopes of each graph were listed, and that he could compare them to see one was half the amount of the other.

Similar to Randy, Freddy also *reflected* here, but she also compared the slopes of the two lines. Her experience at this juncture paralleled her earlier experience with the ECRR framework.

11:38 Interviewer: So, uh, you selected one-half a here for what happens to the acceleration when the mass gets doubled. Why did you select this answer?

11:48 Freddy Fazbear: I just thought of the equation for force, that mass times acceleration equals force, so if the force has to stay the same, then it kind of has to compensate somehow, like if you double the mass, then you have to decrease the acceleration, so the whole compensating does stay the same.

At this point in the IVV, Freddy showed she understood the relationship between mass and acceleration when force is constant. Not only that, but she noticed the slope calculations provided within the IVV while she worked on the IVV.

13:16 Interviewer: So, the curser went from here to here. Were you looking at the slopes?

13:18 Freddy Fazbear: Oh…yeah.

13:22 Interviewer: And what were you noticing?

13:24 Freddy Fazbear: They're about half.

13:25 Interviewer: They're about half. So, was your prediction correct?

13:28 Freddy Fazbear: Yeah.

In noticing the slopes here, Freddy compared them to determine her answer was correct, something not all participants were able to do.

Demi Lovato was the only participant to experience the full ECRR framework at Question 2. She also compared the two slopes of her graphs.

13:46 Interviewer: All right, so you selected that with mass being doubled, that the acceleration was going to be the same. (*elicit incorrect*) What was your thinking behind that?

13:54 Demi Lovato: Well, I remember when we were trying to figure out if this was doubled, then you'd try, you narrowed it down to one of the variables. So it was like, if force was doubled, then you would narrow it down to just mass or acceleration is what I was taught, so like we just, we would exclude everything else and just focus on that, so I thought if the mass increased then so would the force kind of thing, so I kind of excluded acceleration from the whole equation. (*reflect through IVV*).

In this portion of the sequence of ECRR, Demi shows some deep *reflection*, albeit incorrect reasoning in this case. The IVV caused her to think, but she mistakenly relied on her previous physics learning from high school rather than use what she just watched in the previous videos. Thankfully, the IVV did not stop the ECRR process at this point.

> 16:14 Interviewer: So, um, how do you know whether your answer was correct from the previous page?
>
> 16:21 Demi Lovato: Well it wasn't. (*confront*)…Uh, the slope here is point two seven and the slope I made was point one two. (*resolve*). But if I had done it accurately, it would have been cut in half. (*reflect through IVV*)
>
> 16:29 Interviewer: Ok. So you did recognize the slope values while you were working on it?
>
> 16:33 Demi Lovato: Yes. (*reflect through IVV*)

In this sequence, Demi experienced the remaining components of the ECRR framework. She realized that her answer was wrong, and used *reflection* to come to this resolution in her thinking.

Unlike most of the other participants though, Peyton selected that when the force was constant and the mass was doubled, that the acceleration would be doubled. At this point, Peyton experienced *reflect* for the first time, though this was through the VEI rather than the IVV.

> 14:00 Peyton Smith: Whenever I see twice, I think 2. But, when this is saying with double the mass, I probably should have put half, because it's double the mass not double the acceleration. (*reflect through VEI*)

She found out that she was wrong through other components of the ECRR framework, namely, *confront* and *resolve*.

16:02 Peyton Smith: My initial answer was not [correct]. (*confront*)

16:04 Interviewer: How do you know?

16:06 Peyton Smith: Because the slope of the line has decreased. (*resolve*)

16:12 Interviewer: From what to what?

16:17 Peyton Smith: Um, pretty much by half. So, I should have put half of a. (*resolve*)

While she didn't notice that the slope measurements were provided, she was able to *resolve* her thinking while completing the IVV.

Across entire IVV ECRR experiences. In the preceding sections, the experiences of the ECRR framework were constrained to sequences surrounding an initial instance of *elicit incorrect*. However, this was not the only way the framework was experienced. In the cases of some participants, the framework was experienced on a more global level within the IVV. For instance, Lily experienced the first three components of the framework after answering Question 1, but did not experience *reflection* in this sequence. However, in responding to Question 2, she began to *reflect,* but did not experience the first three components of the framework. Thus, Lily still experienced all four components of the ECRR framework, but did not experience them sequentially surrounding the same instance of *elicit incorrect*.

While Peggy experienced most of the components of the ECRR framework, interestingly, she did not experience an instance of *elicit incorrect*. This was due directly to experience with the other components of the framework, causing her to *reflect* on her thinking at that moment and choose the correct answer. In some sense, the IVV *confronted* her thinking and helped her come to a *resolve* in that conflict through *reflection*, all in a very short period of time.

07:57 Interviewer: All right, this is interesting. You moved, you initially selected "b" and then you moved to "c". What were you, what were your thought processes in here?

> 08:08 Peggy Carter: Um, I was looking at the graph itself and I, um, corrected myself that it was, like, the cart was always going to be constantly increasing in speed and the original graph that I selected suggested that the speed was going to taper off after a little while and so I switched to “c”, um, knowing that had the rope not been there, it would have just kept going at the constant speed.

In this passage, Peggy did a lot of thinking. She *reflected* on what she had already seen in previous videos. Her *reflection* shows that the IVV did *confront* her thinking and that she came to a *resolve* in that thinking. In Peggy’s case, the act of *reflecting* really caused her to *resolve* conflicts she had, all while completing the N2 IVV.

Pre/Post Misconceptions: Levels of Effectiveness

In looking at all the data, I paid close attention the misconceptions participants had as well as when they had them. Across all 13 N2 participants, they scored 13.99% on the full pre-test and 25.87% on the full post-test, for a Hake’s gain of 0.14, which is low (Hake, 1998). On the three LivePhoto Physics Group questions, they answered 15.4% correct on the pre-test and 48.7%, for a Hake’s gain of 0.39, which is medium. Comparing this data to data obtained from previous work done by the LivePhoto Physics Group (Kathy Koenig, personal communication), the results obtained here are considerably better. The LivePhoto Physics Group collected data at the University of Cincinnati and found a Hake’s gain of 0.17 for the same three questions as my three LivePhoto Physics Group questions, with a pre-test score of 32.8% and a post-test score of 44.3% (see Figure 4.6). This gain is low, versus the medium gain I found using the same three questions. An additional piece of effectiveness that all of this quantitative data does not address is how participants answered Question 2 in the N2 IVV. Eleven of 13 participants answered this question correctly, suggesting that there was some nuance to measuring the effectiveness of the

N2 IVV. In other words, basing its effectiveness on the quantitative measures alone, which actually do not perfectly model the instruction found within the IVV itself, offers an incomplete picture of what students actually did or did not learn. Rather, looking at the addition of the qualitative data for evidence of the N2 IVVs effectiveness actually shows that a majority of the participants did show they learned while completing the IVV in that they can accurately relate a decrease in acceleration with an increase in mass when force remains constant.

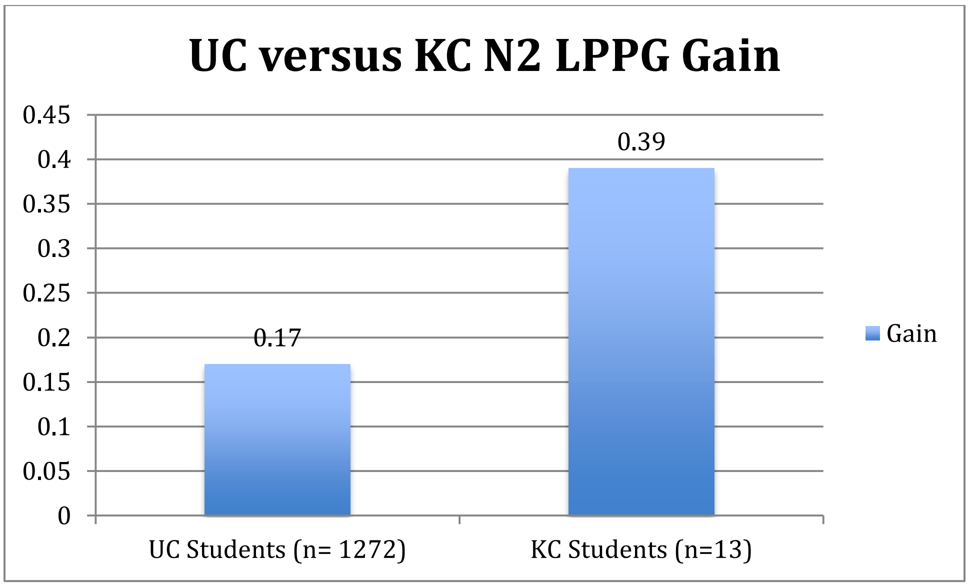

Figure 4.6. UC versus KC N2 LPPG gain.

In looking back at the data from the VEI, a number of participants struggled in answering questions 4-11, all of which required graphing skills and a knowledge of the graphs of force versus time. The graphs found in the N2 IVV were all velocity versus time and perhaps this difference in graph types might explain why most participants struggled to understand how to answer these questions. For this reason, I give more credence to the gain score for the three LivePhoto Physics Group questions than for the instrument as a whole.

In tracking the misconceptions students held before and after completing the N2 IVV, a couple of patterns emerge (see Table 4.3). Table 4.3 combines quantitative data with qualitative data. Since the incorrect answers on the quantitative instrument were coded to describe each misconception attached to all incorrect answers, I tracked which misconceptions existed before and after completing the IVV, at least, according to quantitative data. Adding to this, I coded any misconception found during the VEI and included those misconceptions that were exhibited by a participant after completing the IVV. The first thing to note here is that the *acceleration equals velocity* and *velocity proportional to applied force* misconceptions were present both before and after completing the IVV for most of the participants (see

Table 4.4). This suggests that the N2 IVV was not effective at changing either of these misconceptions. However, the *active force wears out* misconception, when it was exhibited by a participant, was mostly exhibited before completing the IVV but not much after. This suggests that the N2 IVV was at least partially effective at changing that misconception. The remaining misconceptions, *force causes acceleration to terminal velocity, constant force means constant velocity*, and *motion when force overcomes resistance* were exhibited by only a few participants. This means that it was unclear whether the N2 IVV was effective at changing those misconceptions. For instance, the *constant force means constant velocity* misconception was exhibited by four participants after completing the IVV, but not held by a different four participants.

Table 4.3

All N2 Participants' Pre, Post, and VEI Misconceptions.

Participant	Force causes acceleration to terminal velocity	Acceleration equals velocity	Constant force means constant velocity	Motion when force overcomes resistance	Active force wears out	Velocity proportional to applied force
Freddy Fazbear	Pre/Post Test	Pre/Post Test, VEI	VEI	VEI	Pre Test	Pre/Post Test
Lily	Pre/Post	Pre/Post Test	VEI		Pre Test	Pre/Post Test

	Test, VEI					
Randy		Pre/Post Test, VEI				Pre Test
Peggy Carter	Pre Test	Pre/Post Test, VEI				Pre/Post Test
Clarissa Beckham	Pre/Post Test, VEI	Pre/Post Test, VEI			VEI	Pre/Post Test
Evelyn Fierce	VEI	Pre/Post Test	Pre/Post Test, VEI		Pre/Post Test, VEI	Post Test
Marie Skaggs		Pre/Post Test		VEI		Pre/Post Test
Sally	Pre/Post Test, VEI	Pre/Post Test, VEI	VEI		VEI	Pre/Post Test
Demi Lovato		Pre/Post Test, VEI	Pre Test		Pre Test	Pre/Post Test
Evelyn Applegate		Pre/Post Test			Pre Test	Pre Test
Peyton Smith		Pre/Post Test		Pre Test	Pre/Post Test	Pre/Post Test
Eloise	VEI	Pre Test, VEI	VEI	VEI	Pre/Post Test	Pre/Post Test
Renee		Pre Test, VEI	Post Test, VEI		Pre Test	Pre/Post Test

Table 4.4

N2 Misconceptions Timing.

Misconception	Pre-Test (# of students)	Post-Test (# of students)	VEI (# of students)
Force causes acceleration to terminal velocity	5	4	5
Acceleration equals velocity	13	11	8
Constant force means constant velocity	2	2	6
Motion when force overcomes resistance	1	0	3
Active force wears out	8	3	3
Velocity proportional to applied force	12	11	0

In looking across all data types, and in identifying where each misconception was held for each participant, I classified how effective the N2 IVV was in changing student misconceptions. Using both quantitative and qualitative data, there were three distinct levels of effectiveness in terms of changing conceptions: *mostly effective*, *partially effective*, and *not* effective (see Table 4.5). Full instrument Hake's gains were calculated for questions 1-11 and LivePhoto Physics Group Hake's Gains were calculated for questions 1-4 (see appendix A). In order for me to deem the IVV to be *mostly effective* at changing conceptions, the gain scores on the quantitative instrument needed to be medium or high as well as data from the VEI suggesting the participant did not exhibit any misconceptions during the VEI. A level of *partial effectiveness* occurred when a participant either did not have medium to high gains, but the VEI data supported a change in their conceptions, or they had medium to high gains but the VEI data showed little change in their conceptions. For this level of effectiveness, the participant had to have exhibited no more than two misconceptions during the VEI. *No effectiveness* occurred when gains were low to medium and VEI data supported a lack of change in their conceptions. These participants exhibited three or more misconceptions during the VEI. In addition to these measures of effectiveness, at the end of the VEI, each participant was also asked to describe how effective they felt the IVV was in terms of their learning.

Table 4.5

N2 Levels of Effectiveness

Participant	Full Hake's Gain	LivePhoto Physics Group Hake's Gain	VEI change in conceptions	Level of Effectiveness
Evelyn Applegate	0.27	1	Mostly	Mostly
Peyton Smith	0.4	0.67	Mostly	Mostly
Lily	0.1	0.33	Partially	Partially
Peggy Carter	0.2	0.5	Partially	Partially
Randy Osborne	0.13	1	Partially	Partially
Freddy Fazbear	0.1	0.67	Not	Partially

Renee	0.1	0.33	Partially	Not
Eloise	0.22	0.33	Not	Not
Evelyn Fierce	-0.1	0	Not	Not
Sally	0.09	0.33	Not	Not
Clarissa Beckham	0.1	0	Not	Not
Marie Skaggs	0	0	Partially	Not
Demi Lovato	0	0	Partially	Not

Mostly effective. Two participants had medium or high gain scores while also not exhibiting any misconceptions during the VEI: Evelyn Applegate and Peyton Smith. From Evelyn's answers on the pre-test, she exhibited three misconceptions: *active force wears out, velocity proportional to applied force*, and *acceleration equals velocity*. On the post-test, she only showed the *acceleration equals velocity* misconception, having replaced the other two misconceptions with correct conceptions.

During the video elicitation interview, Evelyn exhibited two misconceptions: *active force wears out* and *motion when force overcomes resistance*. In both cases, the evidence from the interview suggests that these seemed to be pre-conceptions rather than conceptions held after completing the IVV. In other words, these were misconceptions she exhibited while she completed the IVV, but not after.

> 19:31 Evelyn Applegate: Like, I was thinking of, like, a balloon where the air just blows out, like I thought that was gonna happen to, you see what I'm saying?...Like I thought it was just gonna ppshh, and then it would go.
>
> 19:41 Interviewer: So just give a sudden burst of a force, but not keeping it a constant force. (*active force wears out*)
>
> 19:42 Evelyn Applegate: That's what I thought was gonna happen…And then when I, when it was in the lab, when they had the fan, then I knew it was gonna be constant, so it helped me understand it better.

In some sense, Evelyn did not show a misconception about what was going to happen but rather a rather nuanced view of what could have happened. She was confused by what the rocket cart would do, since she was unsure that it would actually deliver a constant force. When she watched the videos of the cart in the lab, she was sure of the constant force, and thus, she no longer held this misconception.

Briefly toward the beginning of the VEI, Evelyn showed she held the *motion when force overcomes resistance* misconception.

> 07:02 Evelyn Applegate: when I watched the video, I kind of thought about him being on it. And now I know I was wrong, but I thought it would like, I thought it kind of took off slower and then it sped up, but it sped up at a constant. (*when force overcomes resistance*)

In this passage, Evelyn showed what she held while answering the question in the IVV, while at the same time she explained that she no longer held this view.

From Peyton's answers on the quantitative instrument, she exhibited four misconceptions on the pre-test: *active force wears out*, *velocity proportional to applied force*, *acceleration equals velocity*, and *motion when force overcomes resistance*. On the post-test, she did not exhibit the motion when force overcomes resistance misconception and reduced the number of questions that she exhibited the acceleration equals velocity misconception.

During the video elicitation interview, Peyton exhibited two misconceptions: *active force wears out* and *motion when force overcomes resistance*. In both instances, she did not seem to hold this after completing the N2 IVV.

> 07:40 Peyton Smith: My initial reaction was that the cart hesitated in the beginning and then sped up a lot.

In this case, Peyton showed that while completing the IVV, she held this misconception. In saying this was her initial reaction, though, she insinuated that she did not hold this after finishing the IVV. This process was not without another misconception coming out.

08:02 Interviewer: Ok. So in terms of interpreting graph “b”, graph “b” actually has the highest acceleration at the beginning.

This statement was made immediately following her previous misconception. Both of these misconceptions came as a response to the IVV *eliciting* an incorrect conception from Peyton.

Partially effective. Four participants experienced partial effectiveness in terms of their conceptual change: Lily, Peggy Carter, Randy Osborne, and Freddy Fazbear. All four of these participants exhibited one or two misconceptions during the VEI paired with medium to high gain scores. While identifying misconceptions through the quantitative instrument was clearer, the VEI allowed the participants to explain their thinking more, giving them opportunity to exhibit further misconceptions. For instance, one graph in the N2 IVV showed velocity when the active force wears out. In explaining her thinking regarding this answer, Lily showed an additional misconception that did not show up on the quantitative instrument.

07:01: Interviewer: You selected graph “b.” (*active force wears out*)

07:11 Lily: Because I thought that it goes a little, like, constant speed at first and then just accelerates. I didn’t think that it was, like, “c”, just go accelerate, like right up right away. (*motion when force overcomes resistance*)

11:55 Lily: Uh, the speed? (*constant force means constant velocity*)

21:49 Lily: I still think it’s “d.” (*force causes acceleration to terminal velocity*)

In the case of the *active force wears out* example, Lily chose graph "b", which is a graph that shows velocity over time when the active force wears out. She held this misconception until creating her own graph. In the case of the *motion when force overcomes resistance* example, Lily stated why she answered the way she did and also what the correct graph is, "c", which also matches the graphs she went on to create. In the *constant force means constant velocity* case, Lily answered that the speed remained constant when there was constant force being applied to the cart. She appeared to hold this even after completing the IVV. Finally, in the case of *force causes acceleration to terminal velocity*, Lily's response referred to her thinking on one of the post-test questions, and she verbally states that she still held that misconception after completing the IVV.

Another way participants showed a misconception during the VEI occurred when they misread the instrument. For example, during the video elicitation interview, Randy only exhibited one misconception: *acceleration equals velocity*. It was not until the VEI that he realized he was misreading many of the questions on the instrument and discovered his error.

> 16:20 Randy Osborne: I was on the right track, that it was slowing it down and going about half the speed with more mass on it.

In this instance, the argument could be made that Randy really meant acceleration when instead he said speed. Later during the VEI, he discovered he had been misreading questions from the instrument.

> 22:10 Randy Osborne: 'cause I was thinking it was a velocity over time graph…Oh, I was reading it backwards.

Much to Randy's chagrin, he realized that he had misread the instrument questions and this led to the poor quantitative results after completing the post-test. This misreading of questions 4-11 on the N2 quantitative instrument (see Appendix A) was a common theme across many participants.

Not effective. Seven participants did not experience high gain scores while also exhibiting three or more misconceptions during the VEI: Renee, Eloise, Evelyn Fierce, Sally, Clarissa Beckham, Marie Skaggs, and Demi Lovato. Because the quantitative results were so poor for this group, it is no surprise that there were so many misconceptions held by these seven students after completing the N2 IVV.

From Evelyn Fierce's answers on the quantitative instrument, she exhibited multiple misconceptions both before and after completing the N2 IVV. She held the *active force wears out, constant force means constant velocity,* and *acceleration equals velocity* misconceptions on both the pre- and the post-test. Also, she added the *velocity proportional to applied force* misconception on the post-test.

During the video elicitation interview, Evelyn Fierce exhibited three misconceptions: *active force wears out*, *force causes acceleration to terminal velocity*, and *constant force means constant velocity*. All three of these misconceptions were held after completing the N2 IVV.

> 09:12 Interviewer: All right, so you have selected in this question graph "b". (*active force wears out*)
>
> 02:08 Evelyn Fierce: if it would be increasing or if it would, you know, would like kind of go constant after it started increasing after a while, I wasn't sure (*force causes acceleration to terminal velocity*, mentioned also at 03:11 and 09:26)
>
> 22:57 Evelyn Fierce: the velocity is constant (*constant force means constant velocity*)

Evelyn Fierce chose graph "b" when asked to select what graph she thought the velocity matched, which shows the active force wore out. In the case of the *force causes acceleration to* *terminal velocity* misconception, she mentioned on multiple occasions that she thought the velocity would increase for a while, then be constant eventually. She did not want to give up this misconception. In the case of *constant force means constant velocity*, Evelyn Fierce still believed that the velocity was constant because the acceleration was constant. Further probing into this issue showed that she actually had trouble distinguishing between acceleration and velocity and how they were related to each other.

From Marie Skaggs' answers on the quantitative instrument, she exhibited two misconceptions: *velocity proportional to applied force* and *acceleration equals velocity*. Since she answered all post-test questions exactly how she did on the pre-test, this suggests both misconceptions were also held after completing the N2 IVV.

During the video elicitation interview, Marie Skaggs exhibited two misconceptions: *active force wears out* and *motion when force overcomes resistance*. She only seemed to hold the *motion when force overcomes resistance* misconception after completing the IVV.

> 07:55 Marie Skaggs: I guess because it took, from going from zero to, with the applied force, um it takes a few, like, seconds to actually get momentum and because of that, I thought it was a curved graph instead of the straight line.

The misconception here is quite interesting. On the one hand, during the IVV, she answered this question "b", which is a graph that shows the active force wore out. However, her statement describing why she chose "b" was actually the *motion when force overcomes resistance* misconception, which fits better with graph "e", though neither of these graphs was correct.

One of the more concerning aspects of this group of participants is that four of them were physics students at the time of the data collection, had already received instruction regarding Newton's Laws, and should have had a better understanding of the difference between velocity and acceleration. A further analysis of the physics versus non-physics participants follows later in this chapter, but suffice it to say seeing these four exhibit so many misconceptions both before and after completing the N2 IVV was disheartening.

Participant Perception of Effectiveness. All of the N2 participants felt positive regarding the effectiveness of the N2 IVV, meaning, each participant felt they gained knowledge through completing the IVV, regardless of their type of Hake' gain (low, medium, high). For instance, in two instances, Evelyn Fierce, classified in the *not effective* category, described that she felt the N2 IVV was beneficial to her learning, even though there was no quantitative evidence of this learning through the pre/post-test.

> 00:17 Evelyn Fierce: I think that the video was very helpful to kind of visually see, um, what was going on with, like, Newton's Second Law, kind of seeing it like actually working.
>
> 22:22 Evelyn Fierce: I think it was pretty effective, just to kind of visualize it and kind of see where the points lie as far as like the acceleration was half, or like how they're inversely proportional, I think it helped.

In spite of the confusion that Evelyn felt in answering some of the interview questions, she felt quite positive regarding the effectiveness of the IVV itself. While she was able to speak about the inverse proportionality between mass and acceleration when force was constant, Evelyn still held three misconceptions after completing the N2 IVV. Interestingly, though, this learning did not translate at all to the way she answered questions on the post-test.

Multiple times Eloise, also in the *not effective* category, felt positive regarding how effective she felt the N2 IVV was in impacting her learning and what she liked about the IVV.

> 22:37 Eloise: I thought it helped because, like I said, I'm a visual learner, I was able to, like, see it, like actually happen, whereas like, in class, like if you, like, just read off the power points, it's kind of hard to see how, like, force and mass and acceleration are all, like, intercorrelated together.

To Eloise, the visual nature of the N2 IVV was what helped her learn the most as well as being able to see what was happening along with the graphing activities.

One of the more surprising results of participant perceptions of the N2 IVV's effectiveness is that all participants felt positive toward the IVV, regardless of the learning gains on the quantitative instrument or the misconceptions they held onto during the VEI.

Physics Versus Non-Physics Participants

As mentioned at the beginning of this chapter, six of the 13 N2 participants were enrolled in a physics course when they participated in this research. Prior to their participation, these six students had already received in-class instruction regarding Newton's Laws. They scored higher on the pre-test but did not improve as much on the post-test compared to the non-physics students. This was true for both the full instrument (see Figure 4.7) and the LivePhoto Physics Group questions (see Figure 4.8). However, the physics students' Hake's gain for the full instrument was lower on both the full instrument and the LivePhoto Physics Group questions (see Figure 4.9).

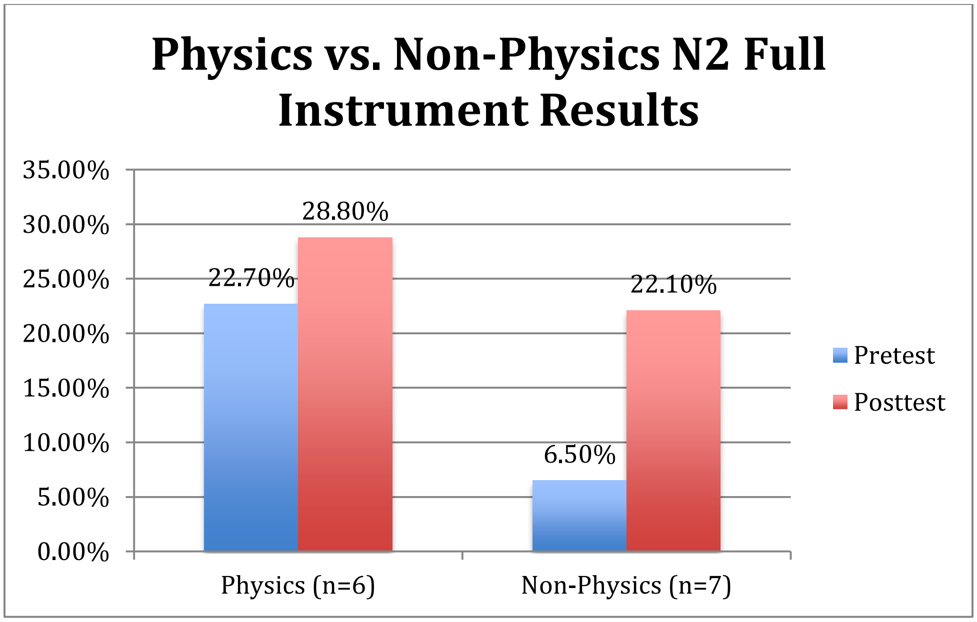

Figure 4.7. Physics Versus Non-Physics N2 Full Instrument Results.

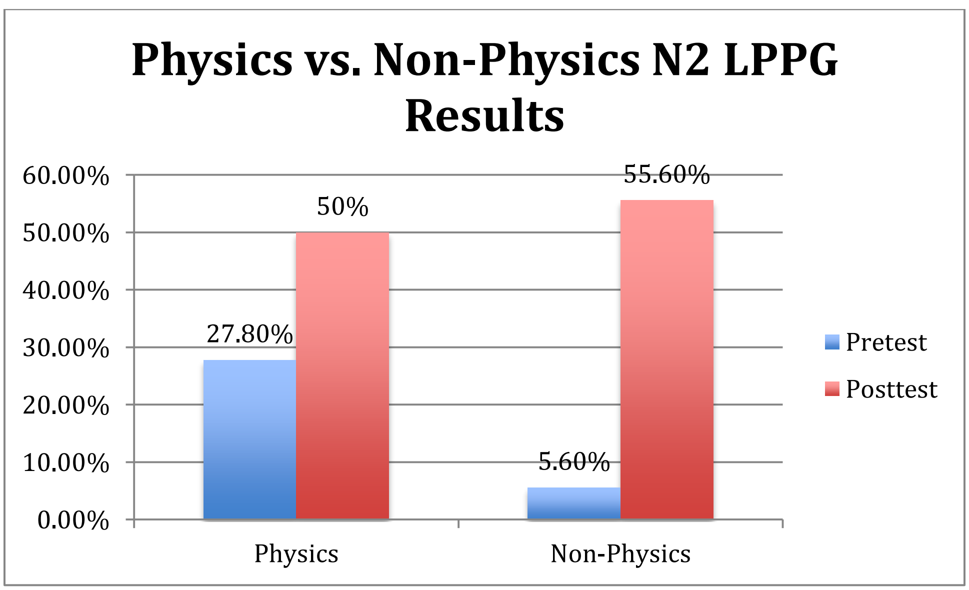

Figure 4.8. Physics (n=6) versus Non-Physics (n=7) N2 LPPG Instrument Results.

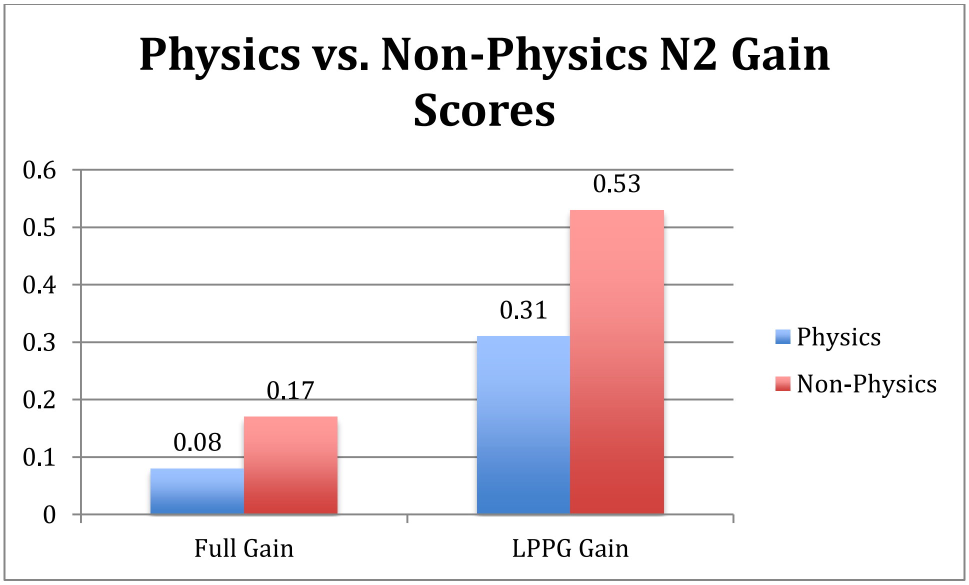

Figure 4.9. Physics (n=6) versus Non-Physics (n=7) N2 Gain Scores for Full Instrument and LPPG Instrument.

For the non-physics students, their pre-test scores were lower than their physics counterparts. This may have allowed them to have more opportunity to improve on the post-test, which they did. On both the full instrument and the three LivePhoto Physics Group questions, the non-physics students outperformed the physics students in terms of the gain. This would suggest that the N2 IVV was more effective for students who had no background physics knowledge than for students currently in a physics course.

Of the six physics participants, five of the six experienced the ECRR framework, two of the six experienced partial effectiveness in the IVV changing their conceptions while the remaining four experienced no effectiveness; and all six answered the final IVV question with ½ a (see Figure 4.4). Of the seven non-physics students, six of them experienced the ECRR framework. Two experienced mostly effective, two experienced partial effective, and three experienced no effectiveness. Five of these participants answered ½ a, while the remaining two answered *a* and *2a*. This all means that both types of students experienced the ECRR framework and a majority of them also answered the final question with ½ a, the correct answer. Qualitatively, the most effective experiences with the N2 IVV occurred among the non-physics participants rather than the physics participants, though both types of students felt they learned through completing the IVV. Combining both data types, then, leads to the conclusion that the N2 IVV was more effective at teaching Newton's Second Law concepts to students not currently enrolled in a physics course than to students who were currently enrolled in a physics course.

Newton's Second Law IVV Summary

Across the 13 participants, almost every student experienced components of the ECRR framework while completing the N2 IVV. However, these experiences did not necessarily lead to a change in their conceptions. This may have been due to the amount of time between instances of *elicit* incorrect and *resolve/reflect*. The N2 IVV did not specifically address or refute each wrong answer in the early question in the IVV. But, most participants realized their mistake in creating the correct graph, although the IVV did not go into detail explaining the meanings behind each incorrect graph. In spite of this, most participants were able to accurately relate the decrease in acceleration with the increase in mass at the end of the IVV. Finally, this IVV seemed to change *active force wears out* misconception to the correct conception, that the active force remains constant, while the remaining misconceptions were not consistently changed across most participants.

Newton's Third Law IVV Findings

There were four common experiences found within the 15 participants who completed the N3 IVV. These experiences were grouped in two major categories: whether the ECRR framework was experienced in full or in part. Within the participants that experienced the full ECRR framework, three further groups were found: effective at changing two primary misconceptions, effective at changing *greater mass* but not *active agent* misconceptions, and not effective at changing either primary misconception. Details of these categories of experience follow a summary of the various segments that make up the N3 IVV.

Summary of N3 IVV

During the first video segment of the N3 IVV, the interviewer, Lori, interviewed different passersby on the street regarding their beliefs about forces during collisions. These passersby watched videos on Lori's iPad. The first situation she presents is a pre-recorded video of a situation where two colliding carts, each with the same mass, hit each other going the same speed. Each passerby in the video predicted that the force would be equal, after which they observed a force versus time graph that showed the forces were equal and opposite (see Figure 4.10).

Figure 4.10. N3 IVV Equal and Opposite Forces.

After seeing the graph in the above figure, the passersby are asked about the forces between objects when both their masses and speeds are different. Before giving the answer, the video on the iPad ends and the next page gives the IVV its first chance to interact with a participant and *elicit* a student conception. This question is essentially the same one posed to the passersby (see Figure 4.11).

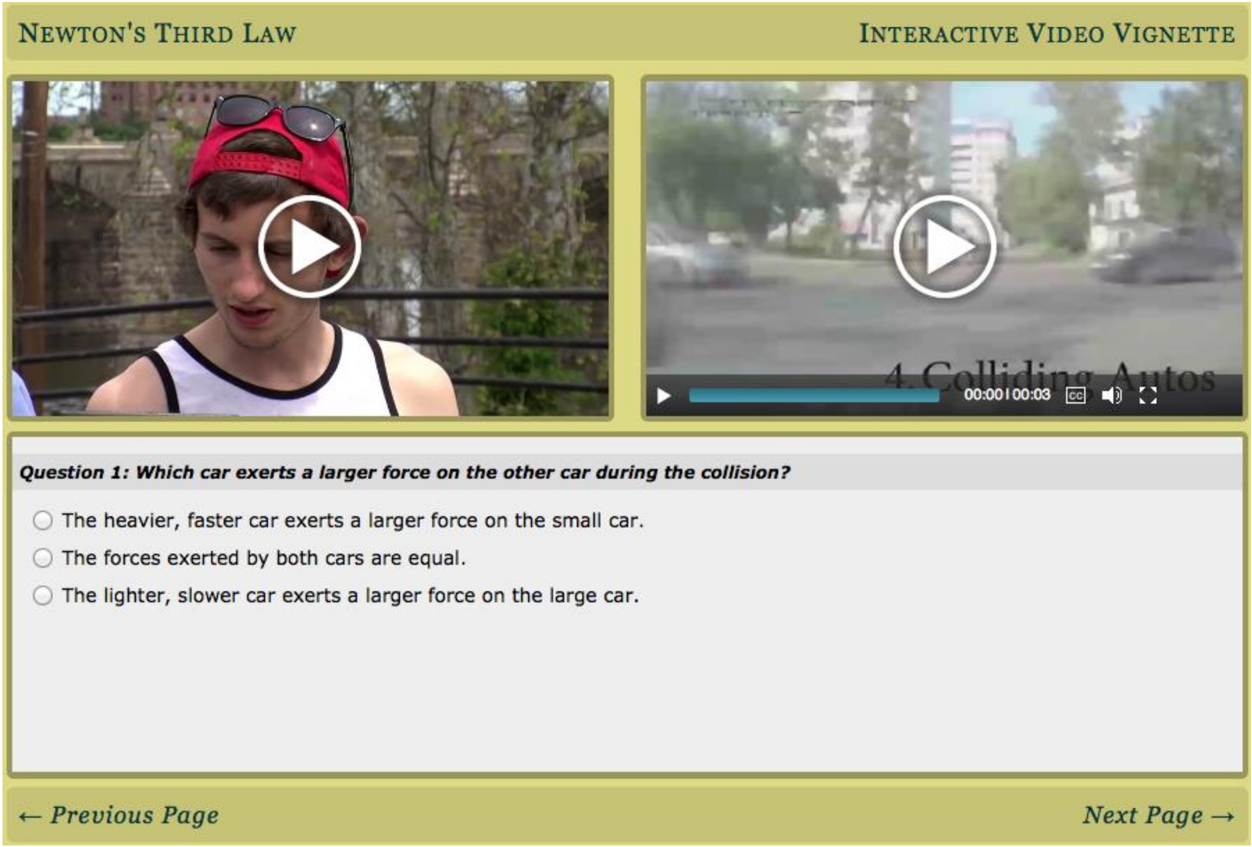

Figure 4.11. N3 IVV Question 1. 2 of 15 (13%) of Students Answered Correctly.

On this page in the IVV, participants answer the question, can look at a video of the collisions in the upper right quadrant, and can watch the responses interviewees had for this question in the upper left quadrant. After answering this question, participants can move on to the next page. The video in this page contains a similar graph to Figure 4.10 (see Figure 4.12). In this portion of the video, both passersby and participants see a graph that looks the same as the one they saw earlier. This graph shows the forces were equal and opposite again and offered the chance for the IVV to *confront* the incorrect conception and then *resolve* this conflict.

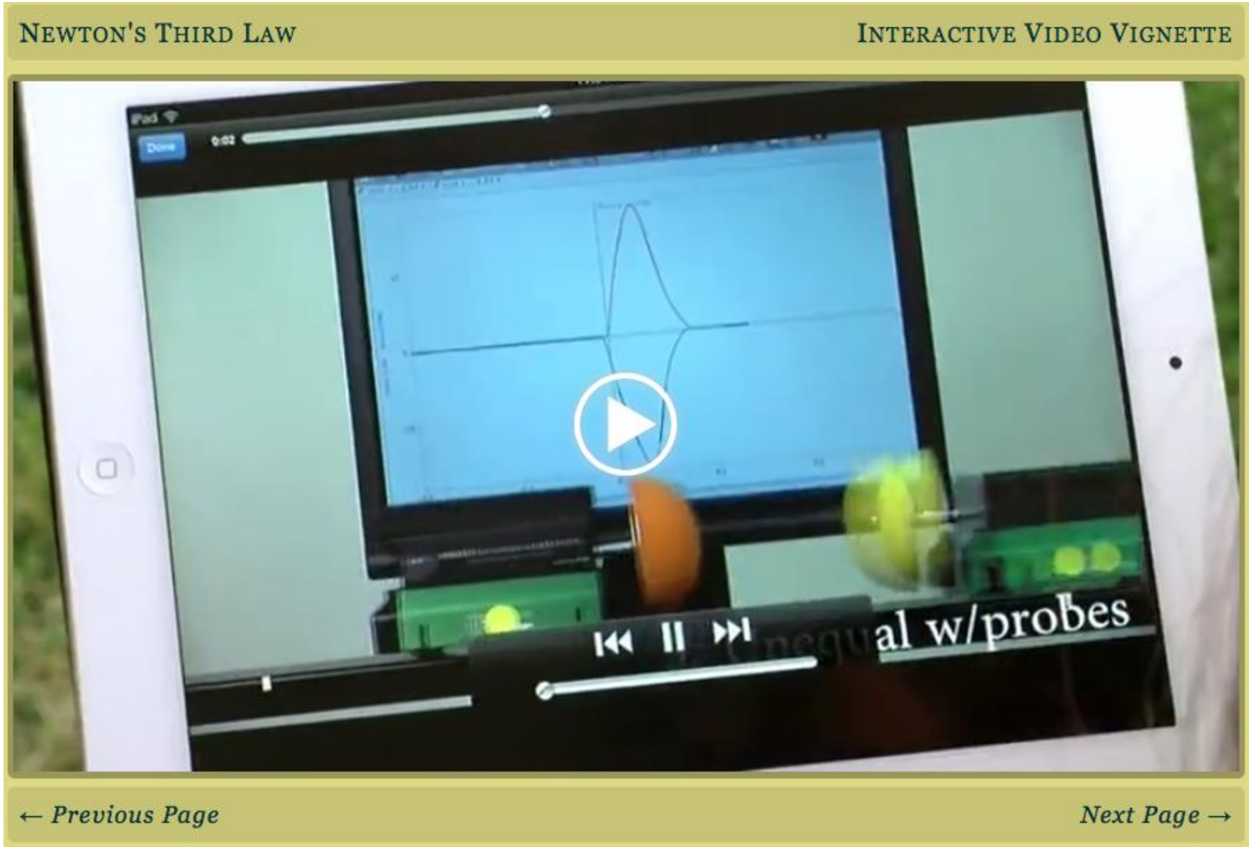

Figure 4.12. N3 IVV Unequal Masses/Speeds Equal and Opposite Forces.

On the next page within the IVV, participants get to see the reactions of the passersby to the graph showing equal and opposite forces. This page shows the participant the answer they gave on Question 1 as well as the opportunity to watch the collision between the two cars again should they choose to (see Figure 4.13).

Figure 4.13. N3 IVV Question 1 Reactions.

After this sequence of question, graph, and reactions, the IVV asks a second question, one in which both participants and passersby are asked which car they would rather be driving (see Figure 4.14). The givens for this question remain the same as for question 1, in that the two vehicles had different masses and different speeds. As with the page containing question 1, this page allowed participants to watch two videos before answering the question: the passerby reactions in the upper left quadrant and a video of the graph in the upper right quadrant.

Figure 4.14. N3 IVV Question 2.

After answering this question, participants move to a page that contains passerby reactions to Question 2 as well as the participant's answer to the question (see Figure 4.15).

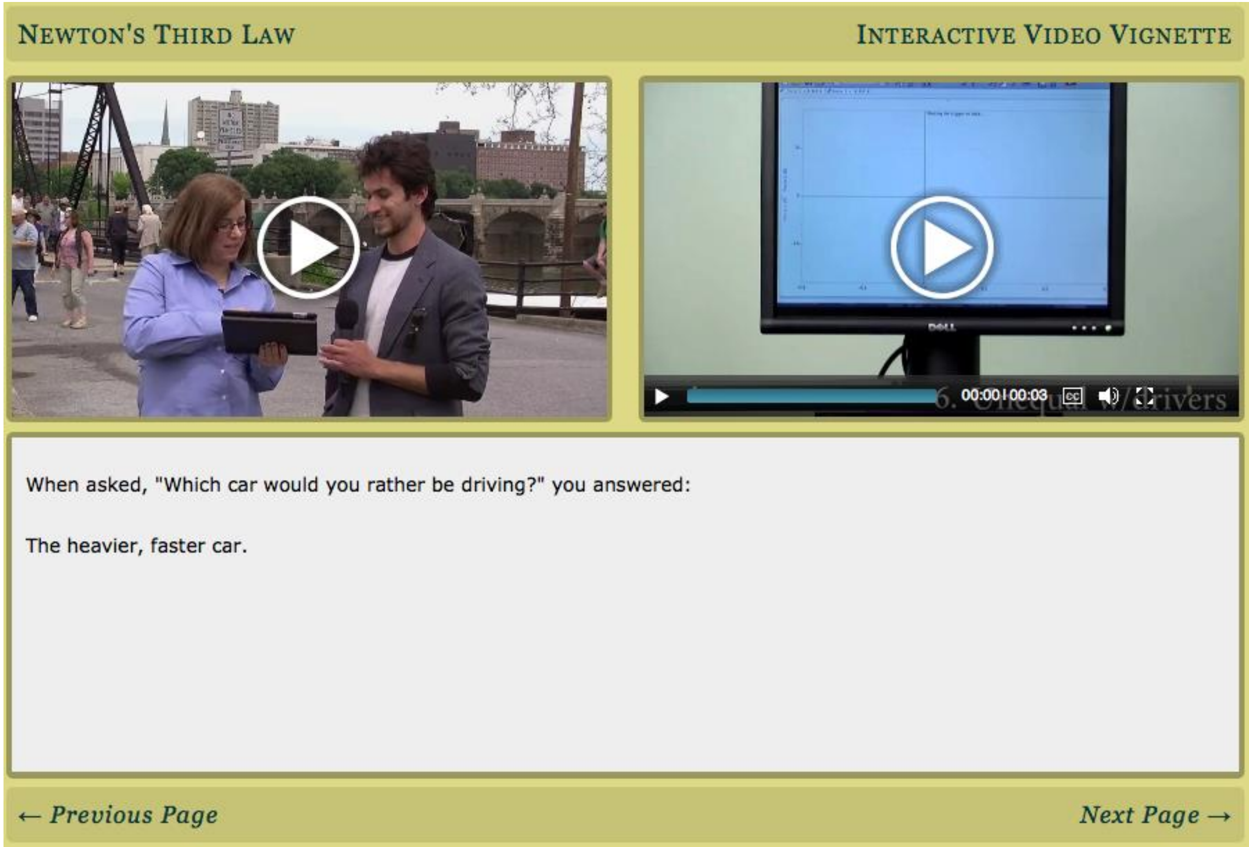

Figure 4.15. N3 IVV Question 2 Reactions.

The final page of the IVV contains a video that summarizes the forces between colliding objects. In this summary, Lori explains that the forces between the two colliding objects will always be the same (see Figure 4.16). Not only that, but she goes on to explain how two objects of different masses can still have the same forces: the accelerations for each object will be different (see Figure 4.17).

Figure 4.16. N3 IVV Summary: Equal and Opposite Forces.

Figure 4.17. N3 IVV Summary: Accelerations.

Where ECRR Can be Found in the N3 IVV

The 15 N3 participants experienced the sequence of the ECRR framework in greater number at Question 1 in the N3 IVV (see Table 4.6) than participants of the N2 IVV. Thirteen participants answered incorrectly at this question and thus, experienced *elicit incorrect* at this point in the IVV. Eight of the 15 participants experienced the complete ECRR sequence starting at Question 1. Two participants did not answer this question incorrectly, and thus could not experience the full ECRR sequence at that question: Clarissa Beckham and Evelyn Applegate. Instead, these two participants *reflected* while completing that section of the IVV. Of the remaining five participants, the IVV *confronted* the wrong answer in all but one case and *resolved* during the IVV twice with one *reflection*. This all means that the N3 IVV participants experienced a greater proportion of the ECRR framework in sequence, leading to support why these participants experienced greater gain scores and more conceptual change as a result of their participation with the N3 IVV.

Table 4.6

N3 Participant ECRR Sequences

Participant	N3 Q1	LPPG Hake's Gain
Eloise	EC RR (both in VEI)	0.75
Evelyn Fierce	ECRR	1
Peggy Carter	ECRR	0.8
Freddy Fazbear	ECR	0.75
Clarissa Beckham	Reflect IVV	1
Evelyn Applegate	Reflect IVV	1
Marie Skaggs	ECRR	0.5
Ariel	ECRR	0.5
El Rato	ECRR	0.67
Mia	E	0.4
Marie	ECRR	0.5
Shannon	EC Reflect in IVV	0.75
Renee Mendenhall	EC Resolve	1
Rosa	ECRR	1
Kristen	ECRR	1

The following sections explain how the participants of the N3 IVV experienced the components of the IVV at Question 1.

Experienced ECRR, Effective

In this category of experience, five participants experienced the full ECRR framework at some point within the IVV and had high gain scores on both the LivePhoto Physics Group questions and the full instrument: Evelyn Applegate, Rosa, Evelyn Fierce, Freddy Fazbear, and Clarissa Beckham (see Table 4.7). Two of these participants (Evelyn Applegate and Clarissa Beckham) did not experience the *elicit incorrect* component of the framework, though their thinking was challenged and they had high gain scores. These participants also did not exhibit either the *greater mass* or *active agent* misconceptions after completing the IVV and VEI.

Table 4.7

Experienced ECRR, Effective, Quantitative Results

Participant	# Correct Pre	# Correct Post	# LivePhoto Physics Group Correct Pre	# LivePhoto Physics Group Correct Post	Full Hake's Gain	LivePhoto Physics Group Hake's Gain
Evelyn Applegate	6	15	3	5	1	1
Rosa	5	15	1	5	1	1
Evelyn Fierce	6	13	2	5	0.78	1
Freddy Fazbear	5	10	1	4	0.5	0.75
Clarissa Beckham	9	15	4	5	1	1

Identified misconceptions. All five of these participants did not exhibit any misconceptions during the VEI. They did, however, mention how their pre-misconceptions changed as a result of completing the N3 IVV.

During the video elicitation interview, Evelyn Fierce exhibited both the *greater mass* and *active agent* misconceptions when the IVV *elicited* incorrect conceptions from her, but these misconceptions were not found after completing the IVV itself.

03:39 Evelyn Fierce: Um, well, I thought the one car would exert a larger one, like, the smaller car, originally.

03:48 Interviewer: Why?

03:49 Evelyn Fierce: Because I thought if it had more weight (*greater mass*), it would probably, um, and it was moving faster than the other car (*active agent*), I thought it would have more force on the other car.

Toward the beginning of the IVV, Evelyn exhibited these two misconceptions, but she did not hold on to these misconceptions beyond this point in the IVV.

During the video elicitation interview, Freddy exhibited three misconceptions: *greater mass, active agent*, and *speed and force (acceleration)*. In the case of the *greater mass* instance, this was found as Freddy relayed her thinking during the IVV.

> 03:12 Freddy Fazbear: I thought that the car with the bigger (*greater mass*), faster speed would have, um, more force, yeah.

In this instance, Freddy showed that she held the misconception during the IVV, rather than after the IVV.

Freddy also exhibited the *active agent* during the IVV much in the same way as the previously mentioned *greater mass* misconception and the second after the IVV.

> 03:12 Freddy Fazbear: I thought that the car with the bigger, faster speed (*active agent*) would have, um, more force, yeah.

In this case, the IVV *elicited* a wrong answer from Freddy, then immediately replaced it with the correct conception.

ECRR framework. Not all of these five participants actually experienced the full ECRR framework, since in the cases of Evelyn Applegate and Clarissa Beckham the N3 IVV did not actually *elicit* an incorrect conception from them. These two participants, though, did experience the remaining components of the framework and have thus been included in this category of experience.

During the VEI, there was not a sequence where the full ECRR framework was enacted for Evelyn Applegate. This was due to the fact that at no point did the IVV *elicit* an incorrect response or incorrect conception from Evelyn Applegate. But this did not mean that she did not learn. On the contrary, her learning was quite evident. Her learning was evident in the amount of *reflecting* that she did throughout her completion of the IVV.

In spite of not *eliciting* incorrect information from Evelyn Applegate, the N3 IVV did still *confront* and *resolve* her thinking. On multiple occasions, she second-guessed herself or decided not to agree with some of the participants within the video.

> 06:29 Interviewer: So what does this graph mean?
>
> 06:30 Evelyn Applegate: It, that they were equal. The forces are equal. And I mean, it was surprising (*confront*), but I was happy that I went with my instinct at the same time.

Evelyn went on to *reflect* on this juncture of the IVV.

> 06:45 Evelyn Applegate: It's like, it's hard to explain. I knew I was, I had, I knew I was right, but because all those people were saying all that stuff, I started to question myself, so when that happened, I was like, yes, I was right. Like a relief, kind of.

In these two passages, Evelyn Applegate showcased the thinking and *reflecting* that went on while completing the IVV, even though she did not exhibit any misconceptions.

Evelyn Applegate also had a number of instances where her thinking was *resolved*. In these cases, she explained that her thinking was confirmed to be correct.

> 12:22 Evelyn Applegate: And it was satisfying to take the multiple-choice test the second time, 'cause I felt like I understood it a bit more.
>
> 21:30 Evelyn Applegate: When I was watching the video, I second-guessed myself, but then I figured out what was right and so then when I took the test the next time I felt more confident.

Even though the IVV did not *confront* misconceptions as in other participants, it still *confronted* Evelyn Applegate's thinking, causing her to *resolve* her own mental conflicts.

As stated earlier, Evelyn Applegate *reflected* on a number of occasions. Almost all of these *reflections* were as a result of watching and participating in the IVV. Here was an example of such a *reflection*.

> 04:56 Interviewer: So why do you think you're right and they are wrong in this case?
>
> 04:59 Evelyn Applegate: I guess it is just my instinct, I just thought it was the right answer based on the example she showed in the first place, and some in my background in physics. I don't know. I just went for it. I just went on a limb and went for it. Is what, that's what came into my mind first, and I was, my parents always told me to just go with your first instinct when you're not sure, and that's what I drew to, so that's why I picked it.

It seems as if Evelyn Applegate was a natural reflector. At many points during the VEI, she described instances where the IVV caused her to *reflect* on her thinking. All of this *reflecting* yielded a complete change in all of her misconceptions she had from before watching the IVV.

In responding to a prompt asking Rosa to describe her reactions to completing the IVV, Rosa showed that she experienced components of the ECRR framework.

> 00:13 Rosa: I thought the bigger car would have more force (*elicit incorrect*), if that makes sense.
>
> 00:31 Interviewer: That makes sense. So how helpful were the videos?
>
> 00:35 Rosa: They were helpful, um, the part where like, showing the formulas or like force equals mass times acceleration, that still kind of confused me (*confront*).

This excerpt showed that the IVV *elicited* a misconception from Rosa as well as caused her mind conflict about that misconception. In her mind, this conflict was still confounding to her mind. Later during the VEI, the IVV went on to further this conflict and begin to *resolve* it.

03:55 Rosa: I thought the bigger one would have more force (*elicit incorrect*), would exert more force I guess.

04:00 Interviewer: Why?

04:02 Rosa: Because it's bigger. (*greater mass* misconception)

04:49 Rosa: But now I know they're equal. (*resolve*)

04:58 Interviewer: So at this point you had first selected equal, then you went to heavier. What were you thinking in here?

05:06 Rosa: Well, in my mind, it made sense that it was heavier, but I was just gonna pick equal because I thought it was a trick question. (*reflect through IVV*)

05:13 Interviewer: A trick question?

05:15 Rosa: But I went with my gut, I guess, which was wrong. (*confront*)

This sequence of interview responses was telling. The IVV *elicited* wrong information from Rosa, *confronted* the misconception, then showed what the correct answer was and why, while also causing Rosa to *reflect* on the process while completing the IVV.

Effectiveness. All five of these participants felt the N3 IVV was highly effective in helping them learn about Newton's Third Law. Evelyn Fierce had many thoughts concerning the effectiveness of the N3 IVV.

12:12 Evelyn Fierce: I thought it was pretty effective. I think they explained their example pretty well. Um, to, like, visually see how, like, the carts, like when they hit each other and what the effect is, I guess.

13:39 Evelyn Fierce: I just feel like this video, even though I didn't get any of the questions in there right, um, I still like, I feel like I learned more from it.

14:43 Evelyn Fierce: I think I'm pretty confident in the after answers…From watching the video, I understood it more so I could answer the questions better.

24:13 Evelyn Fierce: I think the way that they, like, presented the Newton's Third Law was just easier for me to understand and apply than maybe Newton's Second Law.

In the above passages, Evelyn Fierce explained how clear the IVV was in explaining the forces during collisions and how confident she subsequently was in answering questions related to Newton's Third Law. She also mentioned that she learned, even though she answered questions incorrectly while completing the IVV.

Summary. All five of these participants experienced the ECRR framework as well as felt a complete change in their misconceptions regarding Newton's Third Law. These five all had a high Hake's gain on the post-test and did not exhibit either the *greater mass* or *active agent* misconceptions during their VEI. This all suggests that the N3 IVV was effective at changing their misconceptions regarding Newton's Third Law.

Experienced ECRR, Effective at Changing *Greater Mass* but Not *Active Agent*

In this category of experience, four participants experienced the full ECRR framework, had good gain scores from the quantitative instrument, did not exhibit the *greater mass* misconception after completing the N3 IVV, but kept the *active agent* misconception: Ariel, El Rato, Renee Mendenhall, and Peggy Carter (see Table 4.8).

Table 4.8

Experienced ECRR, Effective for GM not AA, Quantitative Results

Participant	# Correct Pre	# Correct Post	# LivePhoto Physics Group Correct Pre	# LivePhoto Physics Group Correct Post	Full Hake's Gain	LivePhoto Physics Group Hake's Gain

Ariel	3	10	1	3	0.58	0.5
El Rato	3	11	0	4	0.8	0.67
Renee Mendenhall	3	12	1	5	0.75	1
Peggy Carter	2	9	0	4	0.54	0.8

Identified misconceptions. Of the two main misconceptions found in Newton's Third Law, *greater mass implies greater force* and *active agent produces the greater force*, these four participants replaced most of their *greater mass* misconception with the correct conception, but still held onto the *active agent* misconception (see **Table 4.9**). In this table, the prevailing pattern is that a greater percentage of the *greater mass* misconceptions were removed compared to the number of *active agent* misconceptions, though both misconceptions decreased in number. Finally, in the VEI, the *greater mass* misconception was not found while the *active agent* was.

Table 4.9

Pre, Post, and VEI Misconceptions

	Pre Misconceptions		
Participant	Greater mass implies greater force	Active agent produces the larger force	Speed and force (acceleration) are equivalent
Ariel	Yes (6x)	Yes (6x)	
El Rato	Yes (7x)	Yes (5x)	
Renee Mendenhall	Yes (6x)	Yes (5x)	
Peggy Carter	Yes (7x)	Yes (6x)	
	Post Misconceptions		
Participant	Greater mass implies greater force	Active agent produces the larger force	Speed and force (acceleration) are equivalent
Ariel	Yes (2x)	Yes (3x)	
El Rato	Yes (2x)	Yes (2x)	

Renee Mendenhall	Yes (1x)	Yes (2x)	
Peggy Carter	Yes (2x)	Yes (4x)	
	VEI		
Participant	Greater mass implies greater force	Active agent produces the larger force	Speed and force (acceleration) are equivalent
Ariel	No	Yes	
El Rato	No	No	
Renee Mendenhall	No	Yes	Yes
Peggy Carter	No	Yes	

From the video elicitation interview, Renee Mendenhall exhibited the *greater mass* misconception during the IVV, but not after. In other words, during the interview, she explained why she believed in the misconception during the IVV, but that she did not hold that belief after completing the IVV. Two other misconceptions, however, were prevalent during the VEI: *active agent* and *speed and force are equivalent*.

On multiple occasions, Renee Mendenhall held onto her belief that a faster or more active object would exert a larger force.

> 18:30 Renee Mendenhall: Well the truck is standing still, so that means it has no acceleration and no velocity. And then the car hits it. So that means that they're not equal.
>
> 19:36 Renee Mendenhall: I chose the force was equal because they weren't moving.

In both of these cases, Renee Mendenhall still believed that speed played a role in the forces between objects during collisions.

On numerous occasions, Renee Mendenhall confused speed with acceleration, which was the *speed and force (acceleration) are equivalent* misconception.

07:09 Renee Mendenhall: so I was thinking that since the mass of that one was greater, and its acceleration was greater, that the force would be greater on the smaller one.

08:48 Renee Mendenhall: Um, well they showed me a video of the equal with the larger mass and acceleration and the vehicle with the smaller mass and smaller acceleration.

14:34 Renee Mendenhall: same mass and acceleration.

In all three of these cases, Renee Mendenhall used the word *acceleration* when she meant *velocity* or *speed*. She explained the given conditions for questions she was asked during the IVV or during the post-test, which mentioned same or different mass and same or different speeds, but did not mention acceleration. It is possible that Renee Mendenhall was referring to the different accelerations on the objects during the collision, but this was unlikely since she was referring to the objects as having those accelerations prior to a collision rather than after. Thus, Renee Mendenhall was exhibiting the *speed and force (acceleration) are equivalent* misconception here.

During the video elicitation interview, Peggy exhibited the same two misconceptions, the *greater mass* misconception prior to completing the IVV and the *active agent* misconception after completing the IVV.

00:25 Peggy Carter: when two cars collide the one would have a greater force on the other.

03:23 Peggy Carter: I thought the larger car would exert a bigger force on the smaller car.

In both of these instances, Peggy showed that before completing the IVV, she believed that the larger mass would exert the larger force. She did not exhibit this misconception at any other point in the VEI.

Peggy did exhibit the *active agent* misconception after completing the IVV.

11:56 Peggy Carter: the answers that were still tricky for me was when there was the smaller car pushing the larger car, it wasn't a collision.

In this passage, Peggy admitted that she still did not understand how to describe the forces between objects in contact with each other when one object was stationary.

ECRR framework. All four participants in the Experienced ECRR, Effective at Changing *Greater Mass* but not *Active Agent* category experienced the four components of the ECRR framework.

During El Rato's VEI, I found two illustrative examples of the ECRR framework. The first instance showed the completed sequence of all four components. The second example came when El Rato was asked about how effective he thought the IVV was in terms of his learning.

Elicit

03:02 Interviewer: Ok, when she asked that question [how do you think the forces will be related?], what did you think the answer was?

03:07 El Rato: I thought the larger car would have the greater force exerted on the smaller car based on Newton's Second Law, considering that the mass was larger on the first, bigger car.

At this point in the IVV, El Rato was asked to compare the forces, and he gave an incorrect response. Thus, the IVV *elicited* an incorrect response. This response showed that El Rato was exhibiting the *greater mass* misconception. He further explained why he believed it, citing his understanding of Newton's Second Law and F=ma.

Confront

05:50 Interviewer: Describe for me your reactions to seeing the graph of the carts colliding.

05:58 El Rato: When I saw the graph, I knew I messed up.

This question was asked just after El Rato and the interviewer finished watching the portion of the N3 IVV where a graph showing the forces between the two cars of unequal mass—the force graph—showed the forces were equal. After seeing this graph, El Rato readily admitted that the video directly *confronted* and refuted his misconception.

Resolve

05:58 El Rato: I didn't think the car that was heavier would have the same force exerted on it.

El Rato quickly learned that the forces during a collision would be the same, no matter the speeds or masses of the colliding objects.

Reflection

05:58 El Rato: I didn't think the car that was heavier would have the same force exerted on it.

In this sequence, El Rato completed the ECRR cycle: he was asked what he thought the forces between the two objects were going to be (*elicit incorrect*), saw a graph that refuted this stance (*confront*), realized his error (*resolve*), and corrected it (*reflect through the IVV*).

Even though the N3 IVV caused participants to experience the entire ECRR framework in sequence, these experiences did not always lead to a change in every misconception. For instance, in Peggy's mind, the *active agent* misconception was not *elicited*, *confronted*, or *resolved* through her participation in the N3 IVV.

11:56 Peggy Carter: Um, the answers that were still tricky for me was when there was the smaller car pushing the larger car, it wasn't a collision, and I was trying to think of like, mass times acceleration and how that would affect the truck, whether the truck had any

> force, because I knew the truck had mass, but it didn't really have its own acceleration. And this video kind of focused, except for the last little portion, on just collisions instead of pushing.

In this sequence, Peggy showed that she *reflected* during the IVV, though the *reflection* was more about what she still did not understand rather than coming to a *resolve* about any conflict in her mind regarding the role speed played in collisions. This was evident when she gave her interpretation of Newton's Third Law.

> 14:22 Peggy Carter: That mass times acceleration, well, the force is in opposite an equal [directions].

Peggy did not include speed in her interpretation of Newton's Third Law, which paralleled her confusion regarding the role speed plays in Newton's Third Law.

Effectiveness. All four participants felt the N3 IVV was effective in teaching them about Newton's Third Law.

During the video elicitation interview, Ariel was interviewed while watching her complete the IVV. After watching the entire IVV, Ariel was prompted to describe her experiences with completing the IVV, including how effective they were in helping her to learn about Newton's Third Law. She responded as follows:

> 13:03 Ariel: I think they were kind of effective. They didn't really, like address the parked car…I think it could have gone, like, into depth more in, maybe I would have understood it a little bit more…I feel like, when the questions like when the cars were going towards each other, I understood those better, but then the question where the car is pushing the truck, I still didn't understand that one.

In this instance, Ariel referred to her inability to answer questions regarding situations involving collisions between one moving object and one stationary object. This meant she was identifying the misconception that the Newton's Third Law IVV was unable to effectively address: the active agent produces the greater force misconception.

El Rato also felt similarly regarding the N3 IVV's effectiveness.

> 11:12 Interviewer: How effective do you think watching these videos and answering those two questions were in helping you learn about Newton's Third Law?
>
> 11:21 El Rato: I think it definitely helped, cause you always, it's kind of a hard thing to think about, like just the concept of it, but seeing like it illustrated in the real-life example kind of helped reinforce Newton's Third Law.

In answering this question, El Rato explained how watching the IVV *confronted* his strongly held misconception, that the video and graph helped him *resolve* the conflict, and finally, that he *reflected* on this process. After the interview, El Rato mentioned how he now knew he had a really strong misconception (*greater mass implies greater force*), and that the IVV was able to help fix it, through *reflection* during the IVV.

Summary. All four of these participants experienced each component of the ECRR framework. They had medium or high Hake's gain scores, and exhibited the *greater mass* misconception less than they did the *active agent* misconception. None of these four exhibited the *greater mass* misconception during the VEI, while three of the four still exhibited the *active agent* misconception. This all suggests that the N3 IVV was more effective at changing the *greater mass* misconception than the *active agent* misconception.

Experienced ECRR, Not Effective

In this category of experience, four participants experienced the full ECRR framework, had medium or high gain scores from the quantitative instrument, but exhibited the *greater mass* and *active agent* misconceptions after completing the N3 IVV: Shannon, Mia, Marie, and Kristen (see Table 4.10).

Table 4.10

Experienced ECRR, Not Effective, Quantitative Results

Participant	# Correct Pre	# Correct Post	# LivePhoto Physics Group Correct Pre	# LivePhoto Physics Group Correct Post	Full Hake's Gain	LivePhoto Physics Group Hake's Gain
Mia	1	7	0	2	0.43	0.4
Marie	4	9	1	3	0.45	0.5
Shannon	3	8	1	4	0.42	0.75
Kristen	4	13	2	5	0.82	1

Identified misconceptions. All four participants in this group exhibited both the *greater mass* and *active agent* misconceptions after completing the N3 IVV. While the predominant theme was for the number of instances of either misconception to decrease from the pre-test to the post-test for these four, both misconceptions were also exhibited during the VEI (see **Table 4.11**).

Table 4.11

Pre, Post, and VEI Misconceptions

	Pre Misconceptions		
Participant	Greater mass implies greater force	Active agent produces the larger force	Speed and force (acceleration) are equivalent

Mia	Yes (7x)	Yes (5x)	
Marie	Yes (5x)	Yes (6x)	
Shannon	Yes (3x)	Yes (5x)	
Kristen	Yes (5x)	Yes (5x)	
	Post Misconceptions		
Participant	Greater mass implies greater force	Active agent produces the larger force	Speed and force (acceleration) are equivalent
Mia	Yes (3x)	Yes (2x)	
Marie	Yes (3x)	Yes (3x)	
Shannon	Yes (4x)	Yes (3x)	
Kristen	Yes (2x)	No	
	VEI		
Participant	Greater mass implies greater force	Active agent produces the larger force	Speed and force (acceleration) are equivalent
Mia	Yes	Yes	Yes
Marie	Yes	Yes	Yes
Shannon	Yes	Yes	
Kristen	Yes	Yes	

Shannon, for instance, exhibited both misconceptions during the VEI. She had an interesting take on the role mass plays in colliding objects.

05:28 Interviewer: What was your reaction when you saw that graph?

05:31 Shannon: I was wrong. I still don't understand it, you know. I was like, how was that even possible. If I ran into a sumo wrestler, it wouldn't be the same force, I mean technically speaking it would be, but you know, I would have got hurt, and he wouldn't, so I was just like, why, how is that possible for it to be the same force if one's clearly bigger and heaver and the other one's smaller and lighter?

Here Shannon showed she was conflicted. She did not want to believe that objects of different masses would exert the same forces on each other. She knew what happens when objects of different masses collide, but she wrongly assumed it is because of the difference in mass, rather than a result of the different accelerations of the two objects.

Shannon extended her thinking about the Sumo wrestler and in doing so exhibited the other misconception, *active agent produces the larger force*.

> 11:28 Interviewer: So, earlier you said if you collided with a Sumo wrestler, you think the force would be different. What does this video have to say about a Sumo wrestler being run into by somebody smaller than a Sumo wrestler?
>
> 11:45 Shannon: I think if it were me, I would probably have to get slingshot into him to make myself go faster than if he were just like, run, a little jog, like jog, or something. So whatever the case might have been, the smaller person would have had to be running faster than the Sumo wrestler.

Shannon mistakenly believed that in order for objects of different masses to exert the same forces on one another, the lighter object must be travelling at a higher speed, a case of the *active agent* misconception.

Mia also was confused by the impact speed had on forces between colliding objects.

> 07:13 Interviewer: What was your reaction to seeing the two carts collide in that mini video?
>
> 07:20 Mia: I kind of knew what was going to happen, because it takes, you have to run, well you have to go a lot faster to make something big move than something little, so that's why the little car flew and big car just kind of scooted up a little after the little car flew away.

07:39 Interviewer: How did you react when you saw the graph containing the forces between the two cars?

07:46 Mia: Um, they were pretty accurate to what I thought.

07:54 Interviewer: So was, did the graph show different forces or the same forces?

07:58 Mia: Different.

08:00 Interviewer: What do you mean different?

08:02 Mia: Um, the force of the big car was a lot more, like it was higher, and in the force of the little car was lower.

Not only did Mia believe that smaller objects must be moving at greater speeds to exert the same force, but she also did not understand the meaning of the graph. For some reason, she was unable to connect that both graphs that she has seen say the same thing—the forces were equal in magnitude and in opposite directions. This meant that the IVV was unable to *confront*, and thus, *resolve* her conflict here.

Mia was also confused about the impact mass had on collisions between two objects of different masses.

16:28 Interviewer: Let's change up the situation a little bit and say what would the forces between two objects be if the smaller vehicle was stationary, parked, and the larger car ran into it, what would the forces be between those two?

16:44 Mia: The forces would be, they would be different, they wouldn't be exactly the same 'cause the car isn't moving. So, I guess the force that the bigger car has on the small one is large and vice versa, the small…

17:00 Interviewer: What if a car of a larger mass is parked and a small car ran into it, what would the forces between those two cars be?

17:09 Mia: Um, the small car wouldn't have any force on the big car. The big car would have force on the little car, even though its not moving, because it's bigger, and it takes a lot more force to make it move.

In attempting to organize her thinking, Mia really did not understand that mass did not play a direct role in the forces between colliding objects, but rather that the mass played a role in the acceleration of each object.

ECRR framework. In the cases of all four of these participants, the ECRR framework was experienced. However, these experiences did not lead to many changes in their misconceptions.

Mia exhibited the ECRR framework on a number of occasions throughout the VEI. In describing her reactions to completing the N3 IVV, Mia responded this way:

00:11 Mia: Well, the answers that I put down the first time were completely opposite of what the video told (*confront*). And after I actually thought about it and saw the videos (*reflect*) that the lady showed, it confirmed (*resolve*) that, you know, what you may think is different from what it actually is (*reflect*).

This passage exhibits the *confront*, *resolve*, and *reflect* components of the ECRR framework. It also shows how closely related these components actually are. [In Mia's VEI, there were also good passages beginning at 01:34, 02:01 and 14:15.] A later passage in the interview exhibited a similar relation.

08:49 Mia: Um, well the forces were the same (*resolve*) now that I'm looking back on it (*reflect, through VEI*)…I guess it just kind of threw me off (*confront*) that the forces were exactly the same, but, in the first video the car didn't fly because they were the same weight. But by the little car being smaller, it flew, but the forces were the same, so I guess it kind of confused me (*confront*), 'cause I'm like, how do they have the same force when they act, when they react completely differently (*reflect, through IVV*). But, I guess that's what the law proves! (*resolve*)

This passage showed the level of thinking and reflecting that the N3 IVV caused in Mia. In going into this detail regarding her thoughts, she appeared to be doing considerable thinking while working through the IVV as well as thinking about the way she answered each question posed during it.

Marie exhibited components of the ECRR framework throughout the VEI. For instance, this framework can be found in a sequence that spanned approximately four minutes of the VEI and multiple video segments.

03:14 Interviewer: So now we have two carts of different masses, or cars of different masses, what did you think the force between those two cars was going to be?

03:23 Marie: That one I thought the bigger one. (*elicit incorrect*)

06:05 Interviewer: Was that a surprising graph, or were you expecting to see it?

06:08 Marie: It was kind of surprising just because the bigger car was also going faster. (*confront*)

06:51 Interviewer: So how did the video you just saw address your answer from the multiple choice question?

07:01 Marie: Um, I was wrong. (*resolve*)

07:07 Interviewer: How does that make you feel?

07:09 Marie: Uh, kind of makes me question it [the answer] (*reflect through IVV*)

In this sequence of the ECRR framework, the IVV *confronted* Marie's misconception that the larger mass would exert a larger force. She saw this when she observed the force graph where the forces on the two carts were equal and opposite of each other. This caused her to question her answer. However, while she *reflected* here, this *reflection* did not extend her knowledge to situations where one object was stationary and the other was moving. She exhibited this during the VEI when talking about how she answered questions from the post-test.

13:56 Interviewer: And we aren't dealing with the same kinds of interactions in some of the other questions, is that what you are saying?

14:03 Marie: I mean, you are, I think I'm more confused about the chair ones, because this one's pushing, so since she's pushing does she have the greater force?

14:19 Interviewer: Suppose the car with the smaller mass is stationary, parked, and the car with the larger mass collides with it. Describe the forces.

14:33 Marie: Well, since the one's not moving, it still has…I would think the one moving.

15:20 Interviewer: What if the larger was parked and a small car ran into it? What would the forces between the two be?

15:34 Marie: Ok, maybe they're all the same. I'm really confused now.

This sequence showed that even though the IVV caused Marie to *reflect*, she was still conflicted about the forces between two objects during collisions.

As with many other participants, the N3 IVV exhibited each piece of the ECRR framework while Kristen completed it.

04:05 Kristen I thought the force of the larger car would be, I thought it would have more force on the smaller one. I thought the big car would have more force on the small. (*elicit incorrect*)

05:54 Interviewer: When you saw this graph, what was your reaction?

05:57 Kristen: I was like, uh, oh, I was wrong and so was everyone else on the video. (*confront*)

06:02 Interviewer: So the forces exerted on each other are?

06:06 Kristen: Equal. (*resolve*)

07:26 Kristen: I'm realizing that force isn't what I thought it was. 'Cause I know even if they have the same force, I know the small car is going to get beat up way worse.

These passages show the typical sequence of the ECRR framework: the IVV *elicited* an incorrect conception (*greater mass*), *confronted* it through the graph, *resolved* it by explaining that the forces end up being equal, and then left the student to *reflect* on the process.

Effectiveness. All four participants felt the N3 IVV was helpful in teaching them about Newton's Third Law. In Shannon's opinion, the N3 IVV was effective in changing her thinking.

00:08 Shannon: The video was interactive, so that was better than me just sitting there watching it.

13:48 Shannon: I think it was really good for the amount of questions that I had in the amount of time, I think it definitely helped. And I would say that I think I did better the second time, definitely, than the first time. But, it was really effective.

14:37 Shannon: Oh, yeah, because it was better to understand. I am really, like, kinesthetic type of learner, videos, and demonstrations and everything that makes things click with me, so if it were longer I probably would have gotten more, that's just the way I learn. Yeah, that was really, that was really effective.

15:02 Shannon: Um, can we show these in class?

Shannon felt that the IVV was a very effective means by which to learn information and especially liked the interactions she participated in throughout the IVV.

Mia also spoke to the effectiveness of the N3 IVV in terms of how much it helped her learn.

> 13:31 Interviewer: How effective do you think this interactive video vignette was in helping you learn about Newton's Third Law?
>
> 13:39 Mia: I think it was very effective. I was, while I was watching I was thinking like, man, if all our classes were taught like this, it would be a lot easier to comprehend, 'cause just in class, you know, going over video and taking notes and hearing somebody talk about it, seeing it and having somebody explaining to me as well is a lot better, so now I'll never forget the third law!

In Mia's mind, the N3 IVV was very effective in teaching her about Newton's Third Law. In her point of view, the N3 IVV was clear in its explanations and very memorable.

Summary. All four of these participants experienced each component of the ECRR framework. They had medium to high Hake's gain scores, but after completing the N3 IVV, still exhibited the *greater mass* and *active agent* misconceptions on the post-test and the VEI. This all suggests that the N3 IVV had little effect at changing either the *greater mass* or *active agent* misconceptions.

Experienced ECRR, Partially Effective at Changing *Greater Mass* but Not *Active Agent*

In this category of experience, two participants did not experience each of the four components of the ECRR framework: Marie Skaggs and Eloise. These two had decent gain scores. Finally, these two participants held both *greater mass* and active *agent* misconceptions after completing the N3 IVV (see Table 4.12).

Table 4.12

Experienced ECRR, Partially Effective at Changing GM not AA, Quantitative Results

Participant	# Correct Pre	# Correct Post	# LivePhoto Physics Group Correct Pre	# LivePhoto Physics Group Correct Post	Full Hake's Gain	LivePhoto Physics Group Hake's Gain
Marie Skaggs	4	6	1	3	0.18	0.5
Eloise	4	9	1	4	0.45	0.75

Identified misconceptions. Both participants in this group exhibited the *greater mass* and *active agent* misconceptions after completing the N3 IVV. The theme for these two participants is that the N3 IVV was unable to change their *active agent* misconceptions, while it was partially able to change their *greater mass* misconceptions (see **Table 4.13**).

Table 4.13

Pre, Post, and VEI Misconceptions

	Pre Misconceptions		
Participant	Greater mass implies greater force	Active agent produces the larger force	Speed and force (acceleration) are equivalent
Marie Skaggs	Yes (7x)	Yes (4x)	
Eloise	Yes (7x)	Yes (4x)	
	Post Misconceptions		
Participant	Greater mass implies greater force	Active agent produces the larger force	Speed and force (acceleration) are equivalent
Marie Skaggs	Yes (5x)	Yes (4x)	

Eloise	Yes (2x)	Yes (4x)	
	VEI		
Participant	Greater mass implies greater force	Active agent produces the larger force	Speed and force (acceleration) are equivalent
Marie Skaggs	No	Yes	Yes
Eloise	No	Yes	

From the video elicitation interview, Marie Skaggs did not exhibit the *greater mass* misconception during the VEI, but did exhibit the *active agent* and *speed and force (acceleration) are equivalent* misconceptions. In describing why she chose some of the answers on the post-test, Marie Skaggs showed her continued misconceptions.

> 14:36 Marie Skaggs: Um, let's see, the car is still pushing the truck…it is still speeding up to cruising speed. For it to speed up the car has to have a greater force than what is being pushed back on it. And that is the amount of force with the car pushes on the truck is greater than that with which the truck pushes back on the car.

In this passage, Marie Skaggs showed that she still believed that the more active agent produces a greater force than the inactive object.

At one point during the VEI, Marie Skaggs believed that speed and acceleration are equivalent.

> 08:25 Marie Skaggs: In the larger car you are less likely to get more whiplash 'cause you're not going, you don't have that bounce-back, whereas in the smaller car, to make up for the fact that it has a smaller force, it bounce, it has a larger velocity, um, in the opposite direction to make it so that, um, the forces are equal.

Marie Skaggs mistakenly believed that in order for the forces to be equal during a collision, the smaller mass must have had a larger velocity.

During the video elicitation interview, Eloise exhibited the *greater mass* misconception both during and after the IVV and the *active agent* misconception after the IVV.

> 00:47 Eloise: I was just assumed that because something had a greater mass that it maybe had a larger acceleration, that it was going to exert, exert a bigger force on another vehicle.
>
> 16:45 Eloise: I want to say that it doesn't have an effect, but I'm gonna go with that the larger one has the…

In the case of the first excerpt, Eloise was relaying her thinking while completing the IVV and in the second case, she was explaining that she still had a belief that the larger mass would exert the larger force. She explained this incorrect conception further.

> 01:00 Eloise: it would exert the same force back on the other vehicle, but the video kind of showed me otherwise.

In this instance, Eloise did not see the video as being different from her thinking, and thus, the IVV did not *confront* this misconception for her.

Later in the VEI, when asked about the impact speed had on the forces during collisions, this is what Eloise thought.

> 17:41 Eloise: I want to say I think it has an impact on it.

At this point, the IVV had already been completed, and Eloise still held that an object with a greater speed exerted a greater force.

ECRR framework. Both Marie Skaggs and Eloise experienced components of the ECRR framework. The N3 IVV did not consistently *confront* or *resolve* each incorrect *elicitation*. Not only that, but some of the *reflections* experienced by the participants came as a result of the VEI rather than the IVV itself.

Marie Skaggs exhibited all four components of the ECRR framework throughout the VEI, but not all of these were experienced during the IVV. Early in the interview, the IVV caused an incorrect *elicitation* regarding the *greater mass* misconception.

> 03:19 Interviewer: So now we have two cars, unequal mass, different velocities, or different speeds. What did you think the force between those two was going to be?
>
> 03:28 Marie Skaggs: I thought with the larger car it would be greater just because watching the reaction, the larger car seemed to have kept going forward even after they crash it and it was pushing the smaller car backwards. Um, and with Newton's Law of, Second Law, mass times acceleration, um, I figured mass played a part in it.

This passage shows how Marie Skaggs went into the IVV believing that a larger mass would exert a larger force on another object. She admitted that she thought mass played a role in causing the forces to be different, showing the *greater forces* misconception. Later during the IVV, this misconception was *confronted*, *resolved*, and caused *reflection*.

> 05:58 Marie Skaggs: I was a little surprised at first (*confront*), um, and in the video it continued and explained it (*resolve*). And then I was like, oh, that makes sense (*reflect*), um, but I was very, pretty much sure that with a heavier mass and a greater velocity it would have a greater force than the smaller car.

This passage showcases the rest of the ECRR framework. The IVV caused Marie Skaggs to *confront* her incorrect conception, *resolve* it, then caused her to *reflect* about it. This would suggest that the N3 IVV was effective at changing Marie Skaggs' conception regarding the role mass plays in forces during collisions. However, it also an incredible passage that directly contradicts the post-test data. Marie Skaggs held onto her two misconceptions in almost every case, according to the post-test. However, according to this passage, she claimed to believe that different masses and different velocities did not cause forces to be unequal during collisions.

Later on during the VEI, Marie Skaggs spoke further about the *greater mass* misconception and how the IVV dealt with it.

> 07:13 Marie Skaggs: Um, it reminds me of, in physics class we actually worked it out that mass doesn't play an effect, and I had kind of forgotten about it, and then watching, um, graphs, and then the responses, it just brought back to memory, and I was like, I wish I had of remembered that like two seconds ago.

This sequence is classified as *reflecting* through the interview. Marie Skaggs *reflected* at this juncture, but the *reflection* did not occur during the IVV but after, during the VEI.

The Newton's Third Law IVV seemed to be able to *elicit* misconceptions from Marie Skaggs, but not all of them were *confronted* and *resolved* during the IVV. This IVV did cause Marie Skaggs to *reflect* during the IVV, but these *reflections* did not always lead to changed conceptions. Also, she *reflected* on a number of occasions as a result of the VEI, changing her conceptions as a result of participating in the research.

Not every component of the ECRR framework was found throughout the VEI with Eloise. There was only one instance of *confront*, with more instances of *resolve* than any other participant. Her *reflections* were split equally between instances of *reflecting* through the IVV and *reflecting* through the VEI. The single instance of *confront* did come in response to an *elicit* and was followed by both *resolve* and *reflect*.

> 06:10 Eloise: at the time I had the same answer (*elicit incorrect*), but now I would, uh, I would pick the other, pick that the forces are equal (*resolve*).

07:15 Interviewer: When you were first watching this video, where they're now measuring the forces on the two carts, what was your reaction to seeing that graph?

07:24 Eloise: I was actually surprised that it was an equal force (*confront*), but then, like now that I look at it, I watch it again, it makes sense. (*reflect through VEI*).

Compared to other participants, the ECRR framework did not work in the same order. Eloise seemed to immediately see her error, but she did not *really* see it until watching the video of herself completing the IVV. In other words, early in the VEI, she seemed hesitant about her answers, but gained more *resolve* to her thinking as the VEI progressed, eventually determining that the forces during collisions were independent of the mass and velocities of those objects.

Effectiveness. Both participants in this category of experience felt the N3 IVV was effective at teaching them about Newton's Third Law.

On two occasions during the VEI, Marie Skaggs spoke about the effectiveness of the N3 IVV.

11:57 Marie Skaggs: I feel like they were very effective, um,…It was, it definitely, um, like you tend to learn more from your mistakes than you do just given the information and regurgitating it, so, um, the fact that they have the questions before the explanation is kind of like, oh, so that's why that works, or that's why I didn't understand that.

After we went over the answers to the post-test, and after finding out many of her answers were still wrong, Marie Skaggs still felt the IVV was effective in helping her learn.

19:43 Marie Skaggs: I still say they were effective. It's just my comprehension may not be as effective.

At the beginning of the VEI, Marie Skaggs was prompted to describe her reactions to completing the IVV.

00:16 Marie Skaggs: Um, well, it was pretty much as I predicted, the first question, uh, had, it tripped me up a little bit (*confront*), but, um, after listening to the explanation afterwards, it made sense (*resolve*), why I made my mistake, but after that, it's pretty much what I expected.

Marie Skaggs insinuated here that what the IVV talked about went along with her thinking. However, the post-test did not back this statement up. And in spite of knowing how she did on the post-test, she still felt she learned a lot.

Likewise, Eloise thought that the N3 IVV was effective at helping her learn about Newton's Third Law.

13:38 Eloise: I thought it was helpful because it put it, like it showed it, like, in person perspective, and then it showed a graph that showed the, um, like forces and it helped explain it. For me, I'm a visual learner, so that really helped rather than just, like, reading it off, like, in your book or something like that.

Interestingly, when asked to compare the N3 IVV with the N2 IVV, Eloise felt the N2 IVV was more effective at helping her to learn, even though she did not learn as much as she thought, according to the post-test scores for either IVV or the gain scores. Also, earlier in the IVV, she said she couldn't remember what the N2 IVV was about, while later, she felt differently.

14:16 Eloise: I definitely think I learned a lot more in this one (N3). I'm trying to think back to, um, 'cause that was with that one…I'm not very good with my memory.

26:22 Eloise: Um, I think I liked the first one (N2) just because it was more interactive and so I was also, like, engaged, like still engaged with it, whereas the other one (N3), like, it was just kind of like…

Eloise enjoyed the interactivity required of the N2 IVV that she felt was not as prevalent with the N3 IVV. She also seemed to have flipped her preference between the two IVVs. Early in the VEI, she seemed to prefer the N3, but by the end changed her opinion to suggest that she liked the N2 IVV better, even though she did not learn as much.

Summary. Both of these participants did not experience each component of the ECRR framework. They had low and medium Hake's gains scores for the full instrument and medium and high gains scores for the LivePhoto Physics Group questions, and exhibited the *greater mass* misconception less than they did the *active agent* misconception. Neither exhibited the *greater mass* misconception during the VEI but both did exhibit the *active agent* misconception. This all suggests that the N3 IVV was more effective at changing the *greater mass* misconception than the *active agent* misconception.

Pre and Post Misconceptions

In determining the effectiveness of the N3 IVV, there are a number of lenses through which to look to address this. In this section, the effectiveness was determined by the Hake's gain scores as well as by tracking the misconceptions all participants held and when they held them, using both the quantitative instrument and the qualitative interview data.

Across all 15 N3 participants, they scored 27.6% on the full pre-test and 72.0% on the full post-test, for a Hake's gain of 0.61, which is medium. On the five LivePhoto Physics Group questions, they answered 25.3% on the pre-test and 81.3% on the post-test, for a Hake's gain score of 0.75, which is high. Comparing this date to data obtained from previous work done by the LivePhoto Physics Group (Kathy Koenig, personal communication), the results obtained here are considerably better (see Figure 4.18).

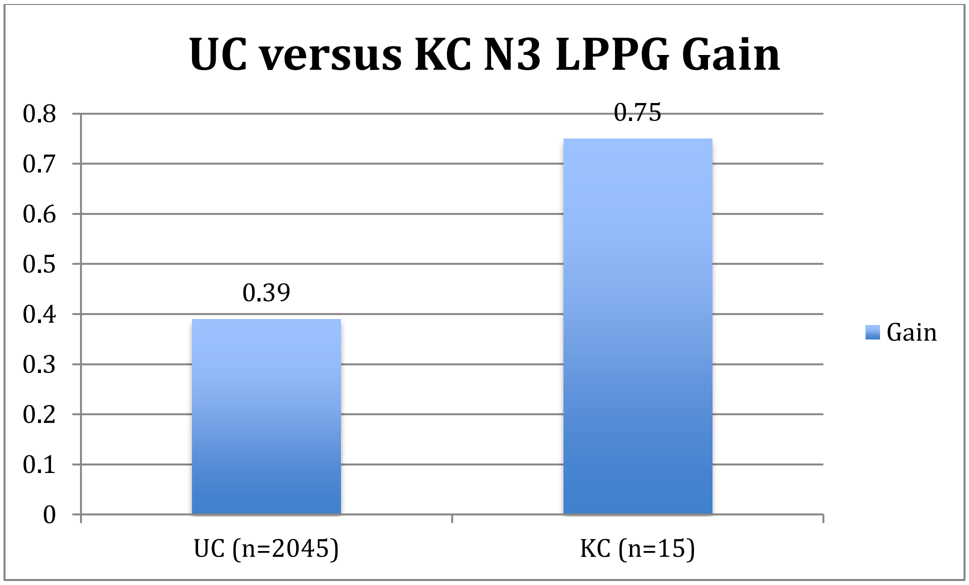

Figure 4.18. UC versus KC N3 LPPG gain.

The LivePhoto Physics Group collected data at the University of Cincinnati found a Hake's gain of 0.39 for the same five questions as my five questions. This gain is medium, versus the high gain I found using the same five questions.

In tracking the misconceptions students held before and after completing the N3 IVV, a few patterns emerged (see Table 4.14). This table combines quantitative data with qualitative data. Since the incorrect answers on the quantitative instrument were coded to describe each misconception attached to all incorrect answers, I was able to track which misconceptions existed before and after completing the IVV, at least, according to quantitative data. In looking at this table, it appears as if the participants, for the most-part, exhibited both the *greater mass* and *active agent* misconceptions on the pre-test, the post-test, and during the VEI.

The numbers in each cell are the pre and post number of instances that an individual exhibited that particular misconception. For instance, Eloise exhibited the *greater mass* misconception seven times on the pre-test and five times on the post-test. Across all 15 participants, they exhibited the *greater mass* misconception on 82 incorrect questions on the pre-test, and just 30 on the post-test, meaning the N3 IVV removed 63% of the instances of this misconception. The *active agent* misconception was found on 71 wrong answers on the pre-test and 29 wrong answers on the post-test, meaning the N3 IVV removed 59% of the instances of this misconception. All 15 participants exhibited both the *greater mass* and *active agent* misconceptions on the pre-test. According to the VEI, four of the 15 participants exhibited the *greater mass* misconception after completing the IVV while nine of 15 exhibited the *active agent* misconception. Combining all of this data together means that the N3 IVV was slightly more effective at changing the *greater mass* misconception than the *active agent* misconception but was still able to change both misconceptions more than half of the time.

Table 4.14

All N3 Participants' Pre, Post, and VEI Misconceptions

Participant	Greater mass implies greater force	Active agent produces the greater force	Speed and force (acceleration) are equivalent
Eloise	Pre/Post Test (7 to 5)	Pre/Post Test (4 to 4), VEI	
Evelyn Fierce	Pre/Post Test (3 to 1)	Pre/Post Test (5 to 1)	
Freddy Fazbear	Pre Test (6)	Pre/Post Test (4 to 1)	
Clarissa Beckham	Pre Test (4)	Pre Test (2)	
Marie Skaggs	Pre/Post Test (7 to 5)	Pre/Post Test (4 to 4), VEI	VEI
El Rato	Pre/Post Test (7 to 2)	Pre/Post Test (5 to 2)	
Marie	Pre/Post Test (5 to 3), VEI	Pre/Post Test (6 to 3), VEI	VEI
Renee Mendenhall	Pre/Post Test (6 to 1)	Pre/Post Test (5 to 2), VEI	VEI
Peggy Carter	Pre/Post Test (7 to 2)	Pre/Post Test (6 to 4), VEI	
Evelyn Applegate	Pre Test (6)	Pre Test (2)	
Ariel	Pre/Post Test (6 to 2)	Pre/Post Test (6 to 3), VEI	

Mia	Pre/Post Test (7 to 3), VEI	Pre/Post Test (5 to 2), VEI	VEI
Shannon	Pre/Post Test (3 to 4), VEI	Pre/Post Test (5 to 3), VEI	
Rosa	Pre Test (3)	Pre Test (7)	
Kristen	Pre/Post Test (5 to 2), VEI	Pre/Post Test (5 to 0), VEI	

Physics Versus Non-Physics Participants

As mentioned at the beginning of this chapter, eight of the 15 N3 participants were physics students when they participated in this research. Prior to participating in this research, these eight students had already received full in-class instruction regarding Newton's Laws. They scored higher on the pre-test both for the full instrument as well as the five LivePhoto Physics Group questions, but did not improve nearly as much on the post-test compared to the non-physics students (see Figure 4.19).

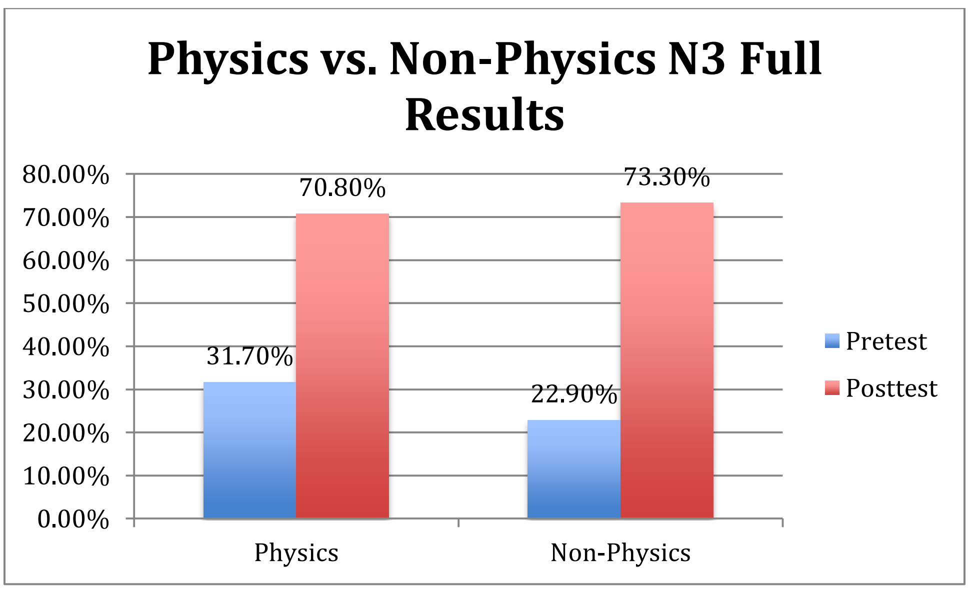

Figure 4.19. Physics versus Non-Physics N3 Full Instrument Results.

This was not true for the five LivePhoto Physics Group questions, where the physics students scored higher (see Figure 4.20).

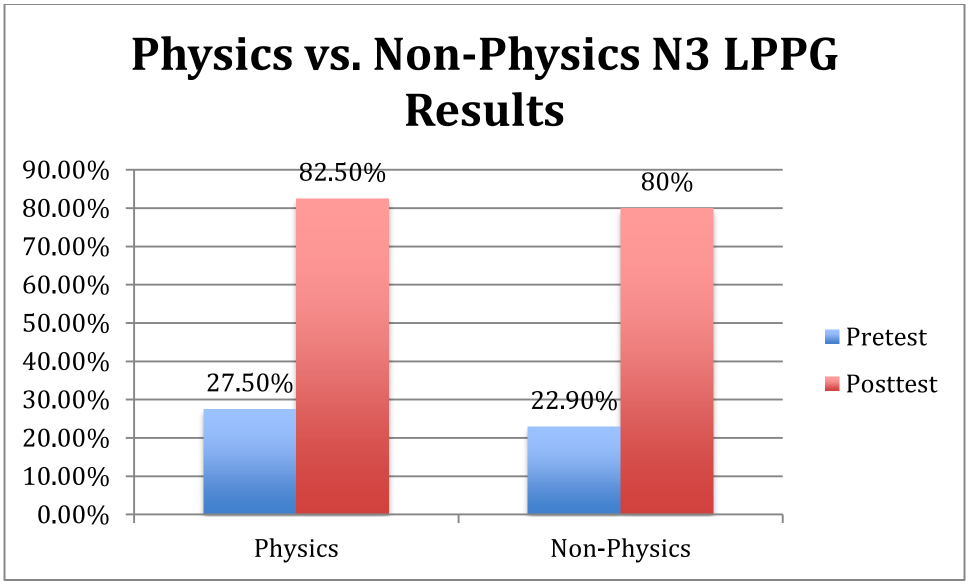

Figure 4.20. Physics versus Non-Physics N3 LPPG Results.

As a result of the them not scoring as high as the non-physics students on the full post-test, the gain score for the physics students was slightly lower than that of the non-physics students on the full instrument but almost equal on the five LivePhoto Physics Group questions (see Figure 4.21).

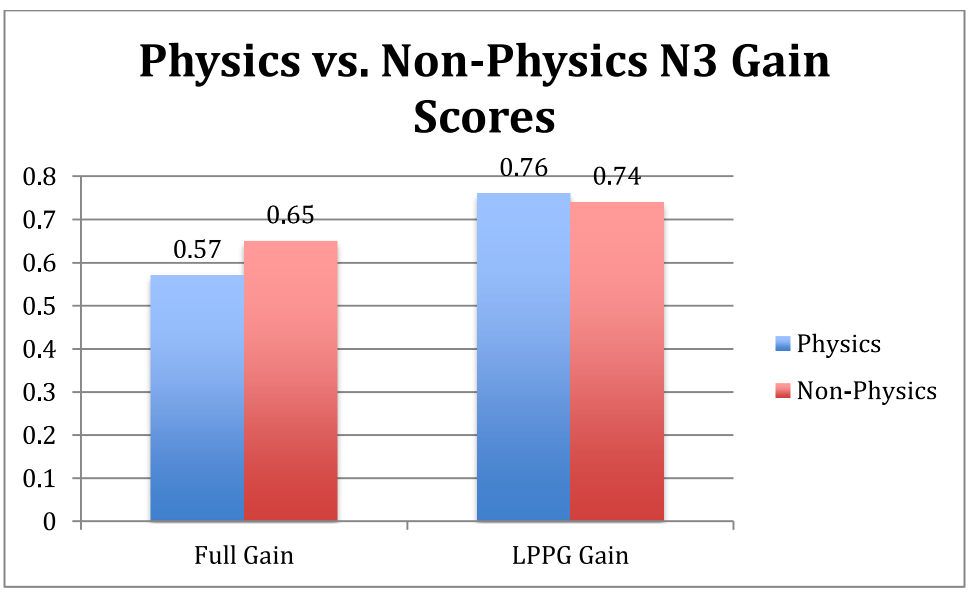

Figure 4.21. Physics versus Non-Physics Gain Scores.

According to the quantitative data, then, the N3 IVV was approximately equal in its effectiveness to change the conceptions of Newton's Third Law, regardless of physics background.

Of the eight physics participants, six of the eight experienced the ECRR framework, three of the eight experienced effectiveness at changing their conceptions, four of the eight experienced partial effectiveness, and one experienced little effectiveness. All seven of the non-physics students experienced the ECRR framework, two of the seven experienced full effectiveness at changing their conceptions, two experienced partial effectiveness, and three experienced little effectiveness. This means that both types of students experienced the ECRR framework. There is little evidence to suggest that the N3 IVV was more effective for either group in terms of changing misconceptions. Put a different way, the N3 IVV was equally effective for physics and non-physics in terms of changing their misconceptions regarding Newton's Third Law.

Newton's Third Law Summary

Across the 15 N3 participants, almost all of them experienced each component of the ECRR framework. These experiences led to the change of many instances of both the *greater mass* and *active agent* misconceptions, though the former seemed to be removed at a slightly higher rate. While completing the N3 IVV, many participants exhibited the *greater mass* misconception while answering a multiple choice question incorrectly in the IVV itself, but these instances were immediately *confronted* and the conflict *resolved*. The experiences at this point in the IVV helped lead to the *greater mass* misconception being changed for most of the participants.

Physics Versus non-Physics Participant Findings

As the previous two major sections elaborated, students that completed the N2 IVV and N3 IVV experienced components of the ECRR framework while completing their given IVV, exhibited certain misconceptions, and had low, medium, and high gains. In this section, I will elaborate on how these experiences were the same or differed by student-type: physics versus non-physics.

Of the 21 participants, nine were physics students and 12 were non-physics. Five of the physics students and two of the non-physics students completed both IVVs. In terms of the data, then, there were 14 instances where a physics student completed an IVV as well as 14 instances where a non-physics student completed an IVV.

The combined data for the each group across both IVVs yielded intriguing findings (see Table 4.15). This table combines all codes of the ECRR framework for each physics and non-physics student as well as lists the Hake's gain for the full instrument and LivePhoto Physics Group questions. This table combines data collected from both the N2 and N3 IVVs. Of the 28 full data sets, 14 belong to physics students and 14 belong to non-physics students. This means that the larger number in this table means that group of students experienced that ECRR component more frequently than the other group of students. This means that the two IVVs combined to *elicit* more incorrect answers from the non-physics students than the physics students, and that these incorrect conceptions were *confronted* to a greater degree for the non-physics students than the physics students. However, the physics students experienced a greater amount of *resolve* in their thinking and *reflected* more during the VEI than the non-physics students. The non-physics students appear to have *reflected* during the IVV more frequently than the physics students. Finally, the Hake's gains for both the full instrument and the LivePhoto Physics Group questions were nearly identical for both groups of students. All of this suggests that the two IVVs were almost equally effective at changing student conceptions regardless of physics background even though the experiences of the ECRR framework differed slightly.

Table 4.15

Full ECRR Code Counts and Hake's Gains Grouped by Student-Type

N2 & N3							
Code	Elicit incorrect	Confront	Resolve	Reflect VEI	Reflect IVV	Full Hake's Gain	LivePhoto Physics Group Hake's Gain
Physics Students	29	45	69	38	68	0.38	0.62
Non-Physics Students	37	53	57	25	74	0.42	0.62

While the comparisons made between the two groups in the previous two major suggestions does suggest, there is more nuance to the differences between how each group of students experienced each IVV. To do this, I looked at how each IVV was experienced by each group as a whole. It was in looking at each IVV separately that differences were found.

In looking at how the physics students and non-physics students experienced the N2 IVV as whole groups, it appeared as if the N2 non-physics participants experienced all components of the ECRR framework more frequently than their physics counterparts except of *reflect through the IVV* (see Table 4.16). More incorrect conceptions were *confronted* and *resolved* for the non-physics students than the physics students. The IVV helped each group *reflect* during the IVV, but the non-physics students *reflected* more during the VEI. The physics students exhibited the *terminal velocity* misconception more than the non-physics students, while the non-physics students exhibited the *acceleration equals velocity* misconception more during the IVV. The remaining misconceptions were exhibited by each group of participants in nearly the same number of instances.

Table 4.16

N2 Experiences and Gain Scores Grouped by Student-Type

N2	Physics Students	Counts per Student	Non-Physics Students	Counts per Student
Elicit Incorrect	11	1.833	17	2.429
Confront	13	2.167	17	2.429
Resolve	13	2.167	24	3.429
Reflect VEI	11	1.833	16	2.286
Reflect IVV	34	5.667	34	4.857
Terminal Velocity	12	2	4	0.571
a=v	5	0.833	10	1.429
Constant force means constant velocity	3	0.5	3	0.429
Overcomes resistance	5	0.833	3	0.429
Active Force	2	0.333	4	0.571
Full Hake's Gain	0.08		0.17	
LivePhoto Physics Group Hake's Gain	0.31		0.53	

All of this helps to explain that from a quantitative perspective, the N2 IVV was more effective at teaching the non-physics students about Newton's Second Law than the physics students. It is true that the physics students answered more pre-test questions correctly than did the non-physics students (see Figure 4.7), but the non-physics students learned more through the N2 IVV. The qualitative results support this difference as well. The non-physics students experienced the *elicit, confront*, and *resolve* components of the framework more than the physics students did. This suggests why the non-physics students gained more on the post-test than the physics students.

The experiences of each group with the N3 IVV were different than those with the N2 IVV. While the non-physics students experienced *elicit incorrect* and *confront* more frequently than the physics students, the physics students experienced more *resolve* (see Table 4.17).

Unlike the N2 IVV, the physics students *reflected* more during the VEI than the non-physics students, who in turn *reflected* more during the IVV. Somewhat surprisingly, the physics students exhibited both major misconceptions, *greater mass* and *active agent* more during the VEI than did the non-physics students. All of this, though, did not seem to make the gain scores different for each group. Put another way, both the physics and non-physics students had high gains on the five LivePhoto Physics Group questions and medium gains on the full instrument. All of this suggests that the N3 IVV was equally effective at changing the conceptions of physics and non-physics students.

Table 4.17

N3 Experiences and Gain Scores Grouped by Student-Type

N3	Physics Students	Counts per Student	Non-Physics Students	Counts per Student
Elicit Incorrect	18	2.25	20	2.857
Confront	32	4	36	5.143
Resolve	56	7	33	4.714
Reflect VEI	27	3.375	9	1.286
Reflect IVV	34	4.25	40	5.714
Greater Mass	17	2.125	13	1.857
Active Agent	14	1.75	7	1
Full Hake's Gain	0.57		0.65	
LivePhoto Physics Group Hake's Gain	0.76		0.74	

Participants that Completed both N2 and N3 Findings

As mentioned earlier, seven participants completed both the N2 and N3 IVVs. Two of them completed the N3 IVV prior to the N2 IVV (Marie Skaggs and Evelyn Applegate), and the remaining five completed the N2 IVV then the N3 IVV (Evelyn Fierce, Freddy Fazbear, Peggy Carter, Eloise, and Clarissa Beckham). Five of these seven students were current physics students while two were not (see Table 4.18). Most of these seven participants experienced the full ECRR framework while completing the N2 IVV. Their Hake's gains on the full instrument ranged from -0.1 to 0.27, all low gains. Their gains on the three LivePhoto Physics Group questions ranged from 0 to 1, with three low gains, three medium gains, and one high gain. The levels of effectiveness then ranged from not effective to mostly effective.

Table 4.18

N2 and N3 Participants' N2 Data

Participant	Physics Student	Order of Completion	N2 Experience of ECRR	N2 Level of Effectiveness	N2 Full Hake's Gain	N2 LivePhoto Physics Group Hake's Gain
Marie Skaggs	Yes	N3 then N2	Yes	Not Effective	0	0
Evelyn Applegate	No	N3 then N2	Yes	Mostly Effective	0.27	1
Evelyn Fierce	Yes	N2 then N3	Yes	Not Effective	-0.1	0
Freddy Fazbear	Yes	N2 then N3	Yes	Partially Effective	0.1	0.67
Peggy Carter	No	N2 then N3	Yes	Partially Effective	0.2	0.5
Eloise	Yes	N2 then N3	No	Not Effective	0.22	0.33
Clarissa Beckham	Yes	N2 then N3	Yes	Not Effective	0.1	0

Similar to their experiences with the N2 IVV, these seven participants mostly experienced the ECRR framework (see Table 4.19). The effectiveness of this IVV was either effective or effective at getting rid of the *greater mass* misconception but not the *active agent* misconception. The full Hake's gains for these participants were higher, ranging from 0.18 to 1, with 1 low gain, three medium gains, and three high gains. On the five LivePhoto Physics Group questions, the Hake's gains ranged from 0.5 to 1, with one medium gain and six high gains.

Table 4.19

N2 and N3 Participants' N3 Data

Participant	Physics Student	Order of Completion	N3 Experience of ECRR	N3 Level of Effectiveness	N3 Full Hake's Gain	N3 LivePhoto Physics Group Hake's Gain
Marie Skaggs	Yes	N3 then N2	Yes	GM not AA	0.18	0.5
Evelyn Applegate	No	N3 then N2	Yes	Effective	1	1
Evelyn Fierce	Yes	N2 then N3	Yes	Effective	0.78	1
Freddy Fazbear	Yes	N2 then N3	Yes	Effective	0.5	0.75
Peggy Carter	No	N2 then N3	Yes	GM not AA	0.54	0.8
Eloise	Yes	N2 then N3	Yes	GM not AA	0.45	0.75
Clarissa Beckham	Yes	N2 then N3	Yes	Effective	1	1

During the VEI for their second IVV, each of these seven participants was asked to compare and contrast their experiences with the N2 and N3 IVV. All seven of them preferred the N3 IVV over the N2 IVV and felt more positive toward their learning after completing the N3 IVV.

> 19:53 Marie Skaggs: Um, I would say that the Third Law videos were a little bit better, um, than the Second Law's in explanation, uh, the, both were pretty effective, but I felt like the Third Law was explained a little bit better than the Second Law.
>
> 18:08 Evelyn Applegate: I think Newton's Third Law video was more helpful for the Third Law than this one was for Second Law.
>
> 13:03 Evelyn Fierce: I feel like I liked this one better, but, um, I think it makes more sense to me.
>
> 12:56 Peggy Carter: I liked this one a lot more
>
> 14:16 Eloise: I definitely think I learned a lot more in this one [the N3 IVV].

19:24 Clarissa Beckham: I think I like this one better.

All of these students felt the N3 was easier to understand and that they learned more from it than the N2 IVV.

When pressed to explain their reasoning further, each student went into different levels of detail in their explanation. Both Peggy and Clarissa, for instance, felt the graphing required in the N2 IVV impeded their learning.

> 12:59 Peggy Carter: Um, I, um, I prefer less graphing. I understand it better when it's not all the graphing.
>
> 19:28 Clarissa Beckham: I remember the last one, I had to do a lot more, like graphing and more hands-on stuff…which isn't bad, but through a computer isn't the greatest thing.

In explaining why the N3 IVV was more effective, multiple participants spoke about the way in which the content was structured as being an effective means by which to convey new information.

> 13:03 Evelyn Fierce: The way she explained, like, the very last part with like, the ma equals ma, like ma1 equals ma2. I thought that made a lot more sense than the last, Newton's Second Law.
>
> 24:13 Evelyn Fierce: I think that the way that they, like, presented the Newton's Third Law was just easier for me to understand and apply than maybe Newton's Second Law.
>
> 12:59 Peggy Carter: And I liked this one's simulation videos a little better and there was more, like people responses, like interview responses to help guide how it should go.
>
> 19:28 Clarissa Beckham: so just watching it and watching other people's like, thoughts through it helped, I guess.

In these cases, the participants suggested that the fact that the N3 IVV centered around interviews with people helped them understand the material better. In the N3 IVV, they saw and heard interactions within the video that showed actual conceptual conflict and resolution of that conflict, rather than very little dialogue within the N2 IVV. A contributing factor of the N2 IVV being more confusing could be the length of the IVV itself—it is almost 12 minutes long, while the N3 IVV is closer to seven minutes long.

Sequences of the ECRR Framework Within Each IVV

Up to this point in the findings, experiences of the ECRR framework have been described when a participant experienced any component of the framework at any time during the IVV. In other words, a student experienced the framework during the entirety of the IVV if they experienced each component of the framework at any point in their experience with the IVV, not just in sequence at given points within the IVV. In comparing the experiences of each IVV across all participants, however, I realized I needed to dig deeper into the data to determine how each participant experienced the framework at specific instances within each IVV. There were two such instances in the N2 IVV and one such instance in the N3 IVV. These instances were the major opportunities for an IVV to elicit an incorrect answer from a participant.

In this study, I found two distinct student experiences of the ECRR framework. In one sense, the ECRR framework may be experienced one component at a time across the entire IVV, and any point within the IVV, where an *elicit* and a *resolve* may be experienced five minutes and two videos apart within the IVV. In a different sense, though, the ECRR framework may be experienced sequentially, or completely, beginning at a specific moment within the IVV, where *elicit* is immediately followed by a *confront* and a *resolve* and then a *reflect*, sometimes only taking about a minute to complete the entire order of the framework, rather than taking place across the entire IVV.

Two major takeaways come out of this difference in the ways that the ECRR framework was experienced by students while completing the IVVs. When I first looked at whether the framework was experienced by participants of the N2 IVV, I found that 11 of the 13 N2 participants experienced each component of entire framework at least once through completing that IVV. This was a surprise for me when I looked at the qualitative data, because during the interviews I got the sense that many participants did not feel their conceptions were *confronted* or *resolved* much, but rather, they left the IVV with many of the same ideas they came in with. For those completing the N3 IVV, all 15 N3 participants experienced the entire framework. As this chapter has shown, though, the quantitative results were quite different for these two groups, as the gain score for the N2 IVV was 0.39 (see Figure 4.6) and the gain score for the N3 IVV was 0.75 (see Figure 4.18). Without looking deeper, the conclusion was reached that both IVVs caused participants to experience the ECRR framework, but those experiences did not lead to high gains for the group of N2 participants while these experiences did lead to high gains for the N3 participants. However, many of the student experiences of the ECRR framework during completion of the N2 IVV were across the entire IVV rather than as a sequence. I then decided to look deeper at the data to see if there really were differences in the ECRR experiences or not.

When I looked at sequences of the ECRR framework at points within each IVV where the IVV asked an *elicitation* question of the participants, differences of the ECRR framework emerged. A majority of the N3 participants experienced the complete ECRR framework starting and as a result of Question 1 of that IVV, while fewer than half of the N2 participants experienced the complete ECRR framework at either Question 1 or Question 2 of that IVV. In the N3 IVV, Question 1 of the N3 IVV was able to *elicit* a misconception of most participants, then replace that misconception with the correct misconception, in the span of about a minute within the IVV. Neither question of the N2 IVV was able to consistently do the same thing for the N2 participants. This leads me to conclude that the complete experience of the ECRR framework at a specific juncture within an IVV is crucial to the conceptual change. From a mixed methods perspective, the qualitative data supports the claim that these complete, sequential experiences of the ECRR framework at specific moments within an IVV, rather than across the entire IVV, impacted a greater change in specific misconceptions participants held prior to completing an IVV.

While the N2 IVV did not lead many of its participants to experience the complete ECRR framework at Question 1, it also did not lead to the participants experiencing the complete framework at Question 2 either. Instead, at Question 2, most participants experienced *reflect*, since 11 of the 13 N2 participants answered this question correctly. In answering this question correctly, that the acceleration would be cut in half when the mass was doubled, participants demonstrated that the N2 IVV was effective in teaching them the relationship between mass and acceleration within Newton's Second Law. In finding that a bulk of the N2 participants answered this question correctly, I went back to the FCI and FMCE and did not find any questions relating acceleration to mass in the same way as within the N2 IVV, and thus, my quantitative instrument used as a pre-test and post-test did not have a question measuring this knowledge of Newton's Second Law. This information was only found out through qualitative data collection and would have been missed outside of this mixed methods study. This also means that I had no way of knowing what these participants thought about this particular topic within Newton's Second Law prior to participating in the study. In other words, I do not know how they would have answered

Question 2 prior to completing the IVV to be able to determine for sure whether they learned this concept from the N2 IVV or already knew it prior to completing the IVV.

The sequences or lack of sequences of the ECRR experience also had an impact on whether misconceptions were replaced with the correct conception or not. The incorrect multiple choice options for Question 1 of the N2 IVV describe misconceptions, including *active force wears out, motion when force overcomes resistance, constant force means constant velocity*, and *force causes acceleration to terminal velocity*. At this question, the N2 IVV *elicited* 11 incorrect responses out of 13 participants. Of these 11, the thinking of seven of them were *confronted*, then six of these seven were then *resolved* (see Table 4.2). This means that just 55% of the incorrect responses from students ended in the correct conception replacing the incorrect one. In contrast, at Question 1 of the N3 IVV, 13 of 15 participants answered incorrectly. The thinking of 12 of these 13 participants was *confronted*, then 10 of these 12 were *resolved* (see Table 4.6). This means that 77% of the incorrect responses ended in the correct conception replacing the incorrect one. Put another way, five of 11 (45%) incorrect conceptions at Question 1 of the N2 IVV did not change, while three of 13 (23%) incorrect conceptions at Question 1 of the N3 IVV did not change.

Summary

In this chapter I have summarized student experiences of the ECRR framework through their completion of either or both the N2 or N3 IVV. The ECRR framework was experienced in two distinct ways: (1) in any order and at any time across the entire IVV, or (2) in sequence, beginning at one moment and finishing all four components within moments of each other. In some cases, these experiences led to a change in conceptions while in other cases these experiences did not lead to much conceptual change. In general, he N3 IVV was more effective than the N2 IVV in this endeavor while students that completed both IVVs preferred the N3 IVV over the N2 IVV. The N2 IVV caused ECRR experiences, though these were typically not sequential and the misconceptions participants entered with did not get replaced consistently with the correct conceptions. The N3 IVV caused most participants to experience the ECRR sequentially, and these experiences tended to lead to misconceptions being changed more frequently than their N2 counterparts. The non-physics students experienced the N2 IVV differently than the physics students did, and this led to greater learning gains for the non-physics students. Finally, the participants that completed both IVVs preferred the experiences and structure of the N3 IVV over the N2 IVV.

Chapter 5

Introduction

This chapter presents a summary of the research and important conclusions drawn from the results presented in Chapter 4. I answer the research questions found in Chapter 1. I discuss the major conclusions as they pertain to the literature as well as provide a discussion of the implications for action based on these conclusions. I describe the limitations of the study and recommendations for further research. Finally, I conclude with an overall and conclusion of the entire study.

Summary of the Study

A fully integrated, mixed methods design was used in this dissertation to answer the research questions. Both quantitative and qualitative data were collected iteratively for each participant. Successive data collections were informed by previous data collections. All data was analyzed concurrently. The quantitative strand included a pre/post test that participants took before and after completing a given IVV and was used to measure the effect on learning. The qualitative strand included video of each participant completing the IVV as well as an audio-recorded video elicitation interview after the post-test. The qualitative data collection was designed to describe student experiences with each IVV as well as to see how the ECRR framework was experienced. Collecting and analyzing data in this way helped develop a more complete understanding of how student conceptions of Newton's Second and Third Laws changed through completion of IVVs and how the ECRR framework was experienced.

This dissertation reports how student conceptions of Newton's Second and Third Laws changed as a result of completing Interactive Video Vignettes on these two topics. Through completion of either or both IVVs, participants experienced the ECRR framework at multiple points within the IVVs. The video elicitation interviews for these participants confirmed that these experiences were different for participants during completion of the N2 IVV as compared to participants during completion of the N3 IVV. In general, participants that completed the N3 IVV experienced a more complete sequence of the ECRR framework during that IVV than did participants of the N2 IVV. Not only that, but the Hake's gains were higher for participants of the N3 IVV than for the N2 IVV. These findings, then, help to answer the research questions.

1) What effect do Interactive Video Vignettes have on student conceptions of Newton's 2nd and 3rd laws?

In this dissertation, the N2 IVV caused a medium gain (0.39) in the 13 participants that completed this IVV, while the N3 IVV caused a high gain (0.75) in the 15 participants that completed this IVV.

2) How do student experiences with Interactive Video Vignettes facilitate conceptual change?

Each IVV facilitated conceptual change through attempting to cause conceptual conflict in the participant through interactively asking multiple-choice questions or graphing activities. In the N2 IVV, these conflicts were not consistently *resolved*, while in the N3 IVV, these conflicts were *resolved* in almost every case.

3) How are *elicit, confront, resolve,* and *reflect* experienced by students while completing the Newton's 2nd Law and Newton's 3rd Law Interactive Video Vignettes?

In the N2 IVV, the ECRR framework was experienced most often one component at a time, in any order, and at any time throughout the completion of the IVV. In the N3 IVV, the ECRR framework was experienced most often as a sequence, beginning at a multiple-choice question, and completed within moments of each other.

4) How do qualitative descriptions of similarities and differences in student ECRR experiences relate to quantitative changes in student conceptions? What other explanations of these similarities and differences emerge?

The participants that experienced the ECRR framework sequentially tended to change their misconceptions more frequently as well as have higher individual gain scores. The participants that did not experienced the ECRR framework sequentially, or did not experience each component of the framework at all, tended to hold on to their misconceptions as well as have lower gain scores.

Major Conclusions and Their Relation to the Literature

In answering the four research questions, two major conclusions were reached: (1) while the ECRR framework was experienced in both the N2 and N3 IVVs, these experiences were qualitatively different from each other and these differences help support the differences in quantitative scores on the post-tests for the participants; and (2) both IVVs were able to change certain misconceptions associated with either Newton's 2^{nd} or 3^{rd} laws more than others.

ECRR Experiences

In thinking about this study and what the important findings are, I go back to the reasons to conduct this study in the first place. The LivePhoto Physics Group found that the N2 IVV was underperforming the N3 IVV when using questions from the FCI to measure learning gains (Laws, et al., 2015) and the reasons for these differences were unknown. The ECRR framework was used explicitly to inform the creation of the N3 IVV but only implicitly in the design of the N2 IVV, so the hypothesis was student experiences of this framework may have contributed to a difference in these gain scores. In this dissertation, I have found that such differences do exist and claim that these differences did have an impact on the conceptual change of the participants.

The sequential experiences of the ECRR framework tended to lead the participant to change their conceptions while the across-IVV experiences of the ECRR framework tended to lead participants to keep their misconceptions.

These conclusions are consistent with the literature reviewed in Chapter 2, specifically the Conceptual Change Model (Hewson & Hewson, 1984). According to the Conceptual Change Model, if a student holding an alternative conception (misconception) is unable to *resolve* the conflict between their alternative conception (misconception) and the correct conception, there will not be conceptual change and the student will retain his/her original conceptions. Because the N2 IVV did not adequately *confront* the misconceptions, and then subsequently *resolve* them, this supports my claim that the quantitative results summarized in Chapter 4 suggest that the N2 IVV was only partially effective at changing the misconceptions *elicited* by the IVV. This is consistent with Hewson and Hewson's (1984) work in that they posited that if a conceptual conflict was not *resolved*, conceptual change would not take place. Thus, since the N2 IVV did not cause a *resolve* conflicts, and even inconsistently cause conceptual conflict in the first place, the lack of conceptual change should not be surprising. In contrast, the complete, sequential experiences of the ECRR framework at Question 1 of the N3 IVV are also consistent with Hewton and Hewson's (1984) work, in that the misconceptions *elicited* at that question were *confronted* and *resolved* and thus the misconceptions were replaced with the correct conception as a result of the N3 IVV.

Conceptual Change

The second major conclusion of this study deals with how participant conceptions changed as a result of completing either IVV. As the pre-test scores showed, the participants entered this study having misconceptions regarding Newton's Second and Third Laws. Both the

N2 and N3 IVVs were able to target several specific misconceptions, while some misconceptions were not addressed. In tracking all the misconceptions for each participant, I discovered that each IVV was able to target some specific misconceptions more than others.

Six of the misconceptions reviewed in Chapter 2 related to Newton's Second Law were demonstrated by the 13 N2 participants (see Table 4.3): *force causes acceleration to terminal velocity, acceleration equals velocity, constant force means constant velocity, motion when force overcomes resistance, active force wears out,* and *velocity proportional to applied force.* Not every participant held each misconception, but each misconception was held by at least one participant. Of these six, only *active force wears out* was the misconception that appeared to be changed in most cases. The *acceleration equals velocity* and *velocity proportional to applied force* misconceptions were held by almost every participant both before and after participating in the IVV. The remaining three misconceptions were not clearly changed for a majority of the participants that held these misconceptions prior to participating in this study. The N2 IVV videos, dialogue, and graphs all concentrated on a constant applied force and its impact on acceleration. The misconception held by the participants within the IVV itself was *active force wears out.* In every graph created by a participant, the result was a line with a positive slope, with no curved section at all. The N2 IVV did not explain any of the incorrect answers from Question 1 (see Figure 4.1) and so these misconceptions were not *confronted* on a consistent basis.

As mentioned in Chapter 2, if students are not made aware of the conflict between their misconception and the correct conception, conceptual change will not occur (Hewson & Hewson, 1984). In the case of the N2 IVV, since the wrong answers to Question 1 are not explained, the participant may not realize why their answer was incorrect—they only know that it was incorrect. As Muller (2008) found, the most effective means by which multimedia can change conceptions is to include dialogues between people within the videos that contain explicit references to the common misconceptions on a given topic. Thus, replacing incorrect misconceptions with the correct one is especially challenging for the N2 IVV. The N2 IVV does not contain such explicit references to the common misconceptions regarding Newton's Second Law. Rather, it relies on the idea that participants will eventually put together the fact that a constant force yields a constant acceleration. This is very difficult to achieve and is unlikely to occur (Champagne, Klopfer, & Anderson, 1980; Dykstra, Boyle, & Monarch, 1992; Trowbridge & McDermott, 1981). In order to truly understand the relationship between force and acceleration, participants must have a grasp of the algebra behind graphing as shown in the IVV. Through the interviews with the participants in this study, I was able to determine that many of them struggled with understanding the meaning of the graphs they made, even though they could make the graphs correctly. Even if the graphs are created correctly, this does not mean that students know how to interpret the graph and relate it to Newton's Second Law (Finegold & Gorsky, 1991; McDermott, 1990). In order to replace these misconceptions, I claim that the IVV would need to explain the remaining answers to Question 1, demonstrate why they are not correct, as well as demonstrate what kinds of accelerations would actually yield those graphs. If these misconceptions are not explicitly addressed by the IVV, their persistence in the participants' thinking will prevent them from being replaced (Eryilimaz, 2002). In other words, some misconceptions are very difficult to replace, such as the *motion implies force* misconception (Clement, 1982). The N2 IVV did not explicitly address this misconception, and therefore, participants held on to that misconception.

In Newton's Third Law, participants held three major misconceptions: *greater mass implies greater force, active agent produces the greater force,* and *speed and force (acceleration) are equivalent*. The *speed and force (acceleration) are equivalent* misconception was not measured on the quantitative instrument, and was only found by four of the 15 participants during their VEI. Both the *greater mass* and *active agent* misconceptions were exhibited by all of the participants on the pre-test. While both misconceptions were changed to the correct conception in almost all of the participants, the *greater mass* misconception was changed more frequently than the *active agent* misconception, though both were changed dramatically according to the post-test. During the VEIs, though, the *active agent* misconception was held by more than half of the participants (9 of the 15), while the *greater mass* misconception was held by fewer than half of the participants (4 of 15), supporting the claim that the N3 IVV better changes the *greater mass* misconception to correct than the *active agent* misconception.

During the N3 IVV, the focus of the passersby as well as the participants was on mass rather than speed. In Question 1 of the N3 IVV (see Figure 4.11. N3 IVV Question 1.), the incorrect answer given by 13 of 15 participants was that the heavier, faster car would exert the larger force on the smaller car, an example of the *greater mass* misconception. While the question and the preceding video state that during the collision the larger car was also travelling faster, the participants latched onto the difference of the masses, rather than the difference of the speeds. Some participants understood that the force would be the same regardless of any difference in either speed or mass, while many interpreted the different masses as having no effect on force, and held onto their *active agent* misconception. Instances of this misconception were *elicited* during the VEI when participants were asked a slightly different question about forces during collisions, where one object was stationary and the other was moving. In these cases, many participants held onto the *active agent* misconception, rather than change it. While the IVV *confronted* the wrong answer, it only concentrated on the mass portion of the situation, rather than the speed as well. I believe the *active agent* misconception would be easily fixed with one short additional video: the graph of a collision between two objects of different speeds colliding. This graph would have the same equal and opposite shape from the graphs from previous video segments and would reiterate that Newton's Third Law states that the forces will be equal and opposite in all situations.

In relating these conclusions to the research literature, Muller's (2008) work is most related. Both the N2 and N3 IVVs changed the conceptions of the participants in this study, though to different degrees. The N3 IVV was more effective at changing misconceptions regarding Newton's Third Law than the N2 IVV was at changing misconceptions regarding Newton's Second Law. I claim that there is evidence from the VEI to suggest that at least some of this difference can be attributed to the experiences of the participants with the ECRR framework, in sequence, while completing each IVV. Although the N2 IVV had more moments where participants could interact with the videos, it did not have clear references to misconceptions as Muller (2008) suggests. These two points may be major reasons why not as many participants learned the targeted concepts from the N2 IVV as the N3 IVV. In conclusion then, I extend Muller's (2008) assertion regarding creating videos aimed at changing misconceptions. In order to best change student misconceptions, an interactive video should implement the *elicit, confront, resolve, reflect* framework through including explicit and clear discussions of those misconceptions between people within that video. Any interactions participants have while engaged with such videos should also aim to include explicit references to misconceptions through the same framework.

Implications

This dissertation has a number of implications based on the results found in Chapter 4. These implications range from how to design technology to incorporate the ECRR framework to how to use IVVs effectively.

The first implication centers on the use of the ECRR framework in the design of video technology. In this dissertation, I found that sequential experiences of the ECRR framework were an effective means by which to change conceptions. Thus, creators of instructional technology designed to change conceptions, including future IVVs, should consider this framework when creating videos. These videos should *elicit* incorrect conceptions, *confront* any misconceptions, *resolve* this conceptual conflict, then help the watcher *reflect* in order to extend their knowledge.

While the learning gains for the groups that completed the two IVVs in this study were either medium or high, each IVV could be improved. The N2 IVV does not *confront* the incorrect answers that participants might select at Question 1. This IVV could be improved through branching from this question. Branching would send a participant to a page specifically designed to counter the misconception that was exhibited on that incorrect answer. After completing the interactive components on this page, such as watching a video, they would be directed back to the first graphing activity that is currently the page that follows Question 1. By creating such branching, the N2 IVV would hopefully improve the likelihood that more misconceptions would be replaced with the correct conception.

Even though the group of participants that completed the N3 IVV had a high Hake's gain, they still held on to some of their misconceptions, mostly in situations that extended the information found within the IVV. Since this IVV concentrated on a situation where two cars of unequal mass and unequal velocity collide, additional videos could be created to teach what the forces on the vehicles would be in other situations, such as one vehicle is stationary with one moving, or one vehicle pushes on the other. I believe extensions such as these, especially if they were in a similar format as the N3 IVV is already in, would increase the likelihood that participants would apply Newton's Third Law to all situations the same way.

One of the challenges to the structure of both the N2 and N3 IVVs is that they cover a single physics topic, and in each case, I believe this impacted the IVVs ability to replace all instances of a given misconception. Instead, one way this could be improved upon would be to create future IVVs around a specific misconception. For instance, there could be a single IVV whose purpose is to counter the *motion implies force* misconception. A caveat to this is to ensure that the ECRR framework is explicitly used in the design of these videos.

As more IVVs are designed, I believe we should research their effectiveness through the use of mixed methods. Not only do we need to determine their quantitative effectiveness, we also need to understand how students experience these videos to affirm whether the sequences of ECRR as an effective means to change misconceptions extends beyond this dissertation.

Finally, for instructors that wish to use the N2 and N3 IVVs, an understanding of the limitations of each is beneficial. For instance, in using the N2 IVV, since some misconceptions are not *confronted*, a teacher could have a discussion in class surrounding each wrong answer of Question 1 to help the class learn the meanings and implications of each graph. In using the N3 IVV, an instructor in a lab could set up similar carts in different scenarios, such as one cart is stationary and a moving cart collides with it, and measure the forces between them. Such measurements could reinforce the application of Newton's Third Law in situations that extend the ones found within the N3 IVV.

Limitations

Throughout this research study, a few major limitations stand out as being challenging to overcome. These limitations include issues of measurement, sampling, the IVVs themselves, and the specific structure of the mixed methods design used in this dissertation.

The quantitative instrument used in this dissertation combined questions from two well-known and widely used instruments in physics education: the Force Concept Inventory and the Force and Motion Concept Evaluation (Hestenes, Wells, & Swackhamer, 1992; Thornton & Sokoloff, 1998). While these two instruments have been well researched (Hake, 1998; Ramlo, 2008; Thornton, Kulh, Cummings, & Marx, 2009), not all of the questions I included in my quantitative instrument were adequate measures of student understanding of either Newton's Second or Third Laws. For instance, the questions selected from the FMCE for Newton's Second Law, while measuring understanding of the law itself, did not measure the actual learning of the participants that completed the N2 IVV (see Appendix A, questions 4-11). These questions were included in the instrument I used because I initially thought measuring student graphing skills through these questions would be beneficial to this study, since the N2 IVV focused on graphing. However, the graphs within the IVV dealt with velocity versus time, while the instrument dealt with acceleration versus time. During the VEIs, very few participants realized this difference or even had the required mathematics background to understand this difference. Thus, the quantitative results for the full N2 portion of the instrument were quite low. If I were to conduct this research again, I would look for more appropriate questions to include in the instrument to be able to more accurately measure participant understanding of Newton's Second Law. I would also add a question relating force and acceleration to measure how students might have answered Question 2 prior to participating in this research. Not only that, but I did not perform a factor analysis to determine if the questions on each portion of the instrument really were measuring the same information. The small sample sizes used in this dissertation prevented such analysis. It would be worth the time and effort in a future study to include a larger sample in order to complete an analysis of the instrument itself.

Before starting this study, I initially thought that the physics participants, having had instruction regarding Newton's Laws, would outgain the non-physics participants. Surprisingly, on the N2 IVV, the physics students under-gained the non-physics students. In watching the physics students complete the tasks in the N2 IVV before completing the VEI, it seemed as if they were not as mentally engaged with the N2 IVV as the non-physics students. I observed multiple physics participants that felt they already knew about Newton's Second Law and had nothing left to learn about it. An explicit treatment of the motivational aspects of conceptual change were not explored in this dissertation and would be worth future study. In addition, the differences in quantitative scores may be due to wide differences in pre-test scores with the physics students having less to gain than the non-physics students (see Figure 4.7 and Figure 4.8). The result that the non-physics students outperformed the physics students is surprising in that the usual occurrence is that the stronger, more advanced students tend to outperform and have a higher gain than other students (Hake, 1998). In the case of this dissertation, the stronger, more advanced students were the physics students, since they had high pre-test scores and had received in-class instruction on Newton's Laws prior to this study. Even though they had less to gain given their pre-test score, they should have out gained their non-physics counterparts after completing both IVVs. However, in explaining the differences in gain scores between these two groups on the N2 data, I did not have a large enough sample size to be able to run statistics on whether the differences in scores on the N2 post-test were significant. Performing a *t*-test might offer further surprising results or confirm an actual difference in the two samples. It was somewhat surprising to me that this specific intervention was more effective for those having no background information on the topic compared to a group that was already taught the information. I would have liked to explore this result further with a larger sample. On the other hand, for the N3 IVV, both the physics and non-physics participants performed about the same (see Figure 4.19 and Figure 4.20).

Future Directions

Three major areas of future directions stand out at the conclusion of this research: (1) increasing the sample size to be able to better determine any differences in participant experience of the N2 IVV based on experience levels in physics; (2) expanding this research study to other IVVs to determine if the complete, sequential experiences of the ECRR framework lead to greater change in conceptions compared to lack of such sequential experiences; and (3) using this methodological design to explore how students learn from online homework systems such as provided by Pearson.

As explained in the Limitations section of this chapter, I am interested in exploring further whether non-physics students really do learn more from the N2 IVV than physics students, or whether that was just an anomaly for my sample. Obtaining a larger sample size might help confirm whether or not this was just due to pre-test scores for the non-physics students being lower than the physics students.

The two IVVs used in this study are not the only ones that are worth researching in terms of their effectiveness at changing conceptions and whether students experience the ECRR framework when completing them. For instance, experiences of the Newton's First Law IVV might be interesting to research, since the LivePhoto Physics Group did not find it to have as large an effect on student learning as the Newton's Third Law IVV (Laws, et al., 2015). Likewise, the Projectile Motion IVV had positive effect on learning, so it might be interesting to explore whether students experience the ECRR framework in sequence while completing that IVV as well. Also, I could compare the experiences of the ECRR framework through completion of two IVVs that were designed with the framework explicitly in mind. This would allow me to compare how participants experience the ECRR framework in different contexts. Studies such as these could continue to benefit the design of online videos and other instructional technologies as we move more learning online.

Finally, the methods used in this study may lend themselves to other means of teaching students outside of the classroom. In my own teaching, I use Pearson's MyLabs™ as part of the homework required of students. While this happens to be in mathematics, Pearson also has this for physics (although it is not the only online homework system, by any means). I am curious to video record students completing online homework, where both the screen and what students write down on paper would need to be recorded. Following this recording, the students would participate in a VEI, where they see the video of the screen and what they wrote down simultaneously while being interviewed about what they were doing and why. I am unsure of a quantitative measure of learning here, so a study of this nature may be qualitative only. It would still be enlightening to learn how students participate with and experience online homework environments.

Conclusion

The purpose of this study was to understand what prompted students to change their incorrect conceptions of Newton's Second or Third Laws in response to of an intervention (IVVs) designed to overcome them. The fully integrated mixed methods design used in this study allowed me to connect the participant experiences with the ECRR framework to their conceptual change as well as their learning gains. In particular, the design itself allowed me to research student experiences *while completing* the N2 and N3 IVVs, rather than rely on their recollection of their experiences if I interviewed them hours or days after completing the IVV. Through this research I determined that a complete, sequential experience of the *elicit, confront, resolve, reflect* framework led to the greatest change in student conceptions.

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Appendix A: The Quantitative Instrument[4]

Pre-Conceptions Paper and Pencil Test

Direction: Select the answer you believe to be correct.

1. 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".

As the rocket moves from position "b" to position "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

2. A woman exerts a constant horizontal force on a large box. As a result, the box moves across a horizontal floor at a constant speed "v_0". If the woman doubles the constant horizontal force that she exerts on the box to push it on the same horizontal floor, the box then moves:

a) with a constant speed that is double the speed "v_0" originally
b) with a constant speed that is greater than the speed "v_0" originally, but not necessarily twice as great
c) for a while with a speed that is constant and greater than the speed "v_0" originally, then with a speed that increases thereafter
d) for a while with an increasing speed, then with a constant speed thereafter
e) with a continuously increasing speed

3. A cart experiences a constant net force in the direction of motion. The speed of the cart

a) is constant.
b) continually increases at a constant rate.
c) continually decreases at a constant rate.
d) increases at a constant rate and then remains constant.

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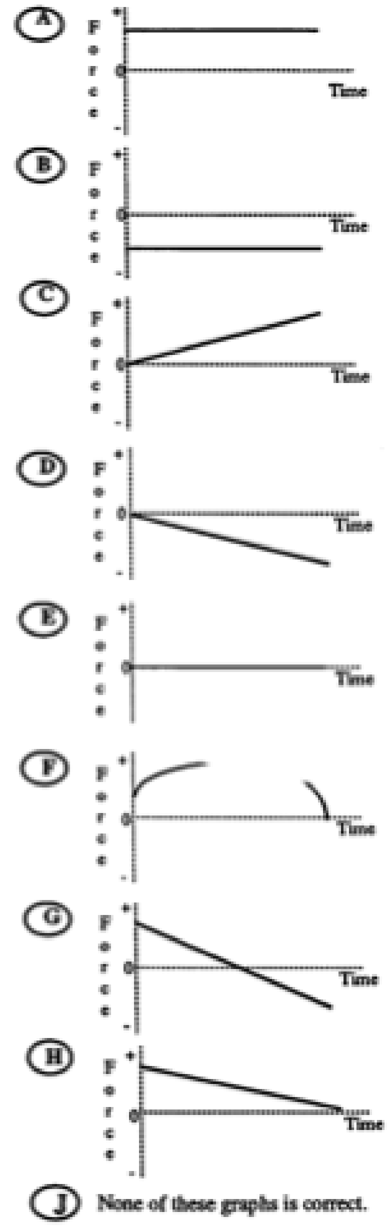
[4] Since the Force Concept Inventory and Force and Motion Concept Evaluation are in the public domain, receiving permission to reprint them in this dissertation is not necessary.

Questions 4-11 refer to a toy car which can move to the right or left along a horizontal line (the positive part of the distance axis).

Assume that friction is so small that it can be ignored.

A force is applied to the car. Choose the one force graph (**A** through **H**) for each statement below which could allow the described motion of the car to continue. You may use a choice more than once or not at all. If you think that none is correct, answer choice **J**.



4. ____ The car moves toward the right (away from the origin) with a steady (constant) velocity.

5. ____ The car is at rest.

6. ____ The car moves toward the right and is speeding up at a steady rate (constant acceleration).

7. ____ The car moves toward the left (toward the origin) with a steady (constant) velocity.

8. ____ The car moves toward the right and is slowing down at a steady rate (constant acceleration).

9. ____ The car moves toward the left and is speeding up at a steady rate (constant acceleration).

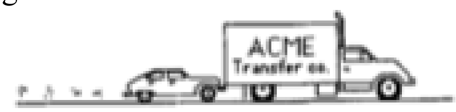
10. ____ The car moves toward the right, speeds up and then slows down.

11. ____ The car was pushed toward the right and then released. Which graph describes the force after the car is released.

12. A large truck collides head-on with a small compact car. During the collision:

a) the truck exerts a greater amount of force on the car than the car exerts on the truck
b) the car exerts a greater amount of force on the truck than the truck exerts on the car
c) neither exerts a force on the other, the car gets smashed simply because it gets in the way of the truck
d) the truck exerts a force on the car but the car does not exert a force on the truck
e) the truck exerts the same amount of force on the car as the car exerts on the truck

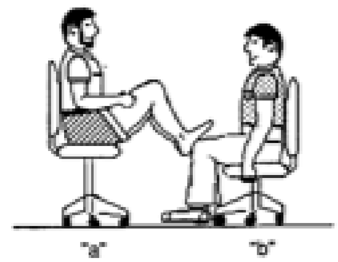
13. A large truck breaks down out on the road and receives a push back into town by a small compact car as shown in the figure below.



While the car, still pushing the truck, is speeding up to get up to cruising speed:
a) the amount of force with which the car pushes on the truck is equal to that with which the truck pushes back on the car
b) the amount of force with which the car pushes on the truck is smaller than that with which the truck pushes back on the car
c) the amount of force with which the car pushes on the truck is greater than that with which the truck pushes back on the car
d) the car's engine is running so the car pushes against the truck, but the truck's engine is not running so the truck cannot push back agains 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 on the other. The truck is pushed forward simply because it is in the way of the car

14. Still dealing with the car pushing the truck from question 13, after the car reaches the constant cruising speed at which its driver wishes to push the truck:
a) the amount of force with which the car pushes on the truck is equal to that with which the truck pushes back on the car
b) the amount of force with which the car pushes on the truck is smaller than that with which the truck pushes back on the car
c) the amount of force with which the car pushes on the truck is greater than that with which the truck pushes back on the car
d) the car's engine is running so the car pushes against the truck, but the truck's engine is not running so the truck cannot 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 on the other. The truck is pushed forward simply because it is in the way of the car

15. In the figure at right, student “a” has a mass of 95 kg and student “b” has a mass of 77 kg. They sit in identical office chairs facing each other. Student “a” places his bare feed on the knees of student “b” as shown. Student “a” then suddenly pushes outward with his feet, causing both chairs to move.



During the push and while the students are still touching one another:

a) neither student exerts a force on the other
b) student “a” exerts a force on student “b”, but “b” does not 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 student exerts the same amount of force on the other

16. A large bowling ball and a small orange are thrown at each other and collide in the air. During the collision:

a) the bowling ball exerts a greater amount of force on the orange than the orange exerts on the bowling ball.
b) the orange exerts a greater amount of force on the bowling ball than the bowling ball exerts on the orange.
c) neither exerts a force on the other, the orange gets smashed simply because it gets in the way of the bowling ball.
d) the bowling ball exerts force on the orange but the orange does not exert a force on the bowling ball.
e) the bowling ball exerts the same amount of force on the orange as the orange exerts on the bowling ball.

Questions 17-21 refer to collisions between a car and trucks. For each description of a collision (17-21) below, choose the one answer from the possibilities **A** through **J** that best describes the size (magnitude) of the forces between the car and truck.

A. The truck exerts a larger force on the car than the car exerts on the truck.
B. The car exerts a larger force on the truck than the truck exerts on the car.
C. Neither exerts a force on the other, the car gets smashed simply because it is in the way of the truck.
D. The truck exerts a force on the car but the car doesn't exert a force on the truck.
E. The truck exerts the same amount of force on the car as the car exerts on the truck.
F. Not enough information is given to pick one of the answers given.
J. None of the answers above describes the situation correctly.

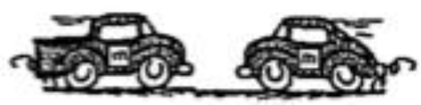
In questions 17-19 the truck is much heavier than the car.

17. ____ They are both moving at the same speed when they collide. Which choice describes the forces?

18. ____ The car is moving much faster than the heavier truck when they collide. Which choice describes the forces?

19. ____ The heavier truck is standing still when the car hits it. Which choice describes the forces?

In questions 20 and 21 the truck is a small pickup and is the same weight as the car.



20. ____ Both the truck and the car are moving at the same speed when they collide. Which choice describes the forces?

21. ____ The truck is standing still when the car hits it. Which choice describes the forces?

Questions 22-25 refer to a large truck which breaks down out on the road and receives a push back to town by a small compact car.

Pick one of the choices **A** through **J** below which correctly describes the size (magnitude) of the forces between the car and the truck for each of the descriptions (22-25).

A. The force of the car pushing against the truck is equal to that of the truck pushing back against the car.
B. The force of the car pushing against the truck is less than that of the truck pushing back against the car.
C. The force of the car pushing against the truck is greater than that of the truck pushing back against the car.
D. The car's engine is running so it applies a force as it pushes against the truck, but the truck's engine isn't running so it can't push back with a force against the car.
E. Neither the car nor the truck exert any force on each other. The truck is pushed forward simply because it is in the way of the car.
J. None of these descriptions is correct.

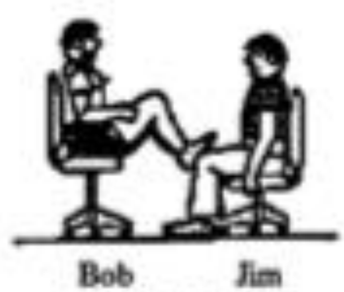
22. ____ The car is pushing on the truck, but not hard enough to make the truck move.

23. ____ The car, still pushing the truck, is **speeding up** to get to cruising speed.

24. ____ The car, still pushing the truck, is at cruising speed and continues to travel at the **same speed**.

25. ____ The car, still pushing the truck, is at cruising speed when the truck puts on its brakes and causes the car to **slow down**.

26. ____ Two students sit in identical office chairs facing each other. Bob has a mass of 95 kg, while Jim has a mass of 77 kg. Bob places his bare feet on Jim's knees, as shown to the right. Bob then suddenly pushes outward with his feet, causing both chairs to move. In this situation, while Bob's feet are in contact with Jim's knees,



A. Neither student exerts a force on the other.
B. Bob exerts a force on Jim, but Jim doesn't exert any force on Bob.
C. Each student exerts a force on the other, but Jim exerts the larger force.
D. Each student exerts a force on the other, but Bob exerts the larger force.
E. Each student exerts the same amount of force on the other.
J. None of these answers is correct.

Appendix B: Newton's Second Law VEI Protocol

Below is a list of questions for post-IVV interviews for Newton's Second Law. These questions are indicative of the questions planned for the qualitative interview, but due to the nature of qualitative research, additional questions may emerge related to the topic based on student responses to initial questions.

Newton's Second Law Correct Post Question Interview Protocol

What does this IVV cause you to think about while completing it?

How is this IVV interacting with or *eliciting* your initial conceptions of Newton's Second Law?

To what degree is this IVV resolving or *confronting* any conflict with your initial conception of Newton's Second Law?

How is this IVV changing or *resolving* your thinking about Newton's Second Law? (If it didn't, why not?)

How did this IVV interact with or *elicit* your initial conceptions of Newton's Second Law?

To what degree did this IVV resolve or *confront* any conflict with your initial conception of Newton's Second Law?

How did this IVV change or *resolve* your thinking about Newton's Second Law? (If it didn't, why not?)

How did this IVV cause you to *reflect* about your learning of Newton's Second Law?

What about this IVV helped your learning?

What about this IVV hindered your learning?

How did this IVV encourage you to change your conception?

Additional Questions

Describe your reactions to completing the IVV.

(ask at 00:48): What did you think of their response at this point? What did you think was going to happen?

(ask at 01:05) What did you observe here?

(ask at 01:33) What did you think would happen?

(ask at 02:05) What did you see happen in the video? What sense did you make of that?

(*confront*) (ask at multiple-choice question 1) What answer did you select and why did you select it? How did the IVV address your answer?

(ask after analysis 1) What shape did your graph produce? How does this compare with your answer to the multiple choice question? What discrepancy was there between the two? How did the IVV address this discrepancy?

(ask at end of video 2) What did you see happen in the video? What happens to the velocity? Does the velocity increase in a steady, uniform manner?

(ask at end of video 3) What answer did you select and why? How did the IVV address this answer?

(ask at 00:20 of video 4) How did the accelerations compare with each other? How did these graphs compare to your answer from the previous page? How did the slopes of the two graphs compare to the answer from the previous page? How did the IVV point these out to you?

How effective do you think the IVV was in helping you to learn about Newton's Second law and why?
What else would you like me to know about your experience completing the IVV?

Appendix C: Newton's Third Law VEI Protocol

Below is a list of questions for post-IVV interviews for Newton's Third Law. These questions are indicative of the questions planned for the qualitative interview, but due to the nature of qualitative research, additional questions may emerge related to the topic based on student responses to initial questions.

<u>Newton's Third Law Correct Post Question Interview Protocol</u>

What does this IVV cause you to think about while completing it?

How is this IVV interacting with or *eliciting* your initial conceptions of Newton's Third Law?

To what degree is this IVV resolving or *confronting* any conflict with your initial conception of Newton's Third Law?

How is this IVV changing or *resolving* your thinking about Newton's Third Law? (If it didn't, why not?)

How did this IVV interact with or *elicit* your initial conceptions of Newton's Third Law?

To what degree did this IVV resolve or *confront* any conflict with your initial conception of Newton's Third Law?

How did this IVV change or *resolve* your thinking about Newton's Third Law? (If it didn't, why not?)

How did this IVV cause you to *reflect* about your learning of Newton's Third Law?

What about this IVV helped your learning?

What about this IVV hindered your learning?

How did this IVV encourage you to change your conception?

Describe your reactions to completing the IVV.

(ask at 00:33 of video 1) What were you thinking at this point? How do the forces compare?

(ask at 02:03 of video 1) What did you think the answer was at this time? How does your answer compare to what you thought when the carts with the same mass collided?

(ask after video 2) What did you think of the four answers you just heard? How do these answers compare with yours for the first multiple-choice question?

(ask after video 3) How did you react when you saw the graph of the two carts colliding?

(ask after video 4) How did the IVV address your answer to the multiple choice question?

(ask after video 5) How did the IVV address your answer to the question about which car you'd rather be driving?

How effective do you think the IVV was in helping you to learn about Newton's Third law and why?

What else would you like me to know about your experience completing the IVV?

Appendix D: Recruitment Script

Kettering College

Volunteers Needed for a Research Study

"Changing Student Conceptions of Newton's Second and Third Laws Using Interactive Video Vignettes"

You have been contacted through email because you are a student in PHYS 141.

The study is open to students in PHYS 141.

The purpose of the research study is to explore your perceptions of *Interactive Video Vignettes* during the Fall semester 2015.

Participation involves two sets of 26 question paper and pencil test, video of you completing an IVV, one set of an 11 or 15 question paper and pencil test, an interview while watching a video of you completing the IVV, and a set of 26 question paper and pencil test.

Time commitment: The questions and interviews will take approximately 75-90 minutes across three total days.

The research will be conducted at Kettering College.

By participating in this research study, you will be given 5 points each of extra credit in the quiz category in PHYS 141 for completing the first and last set of 26 questions. For completing the second and third sets of questions, along with doing the IVV and participating in the interview afterward, you will receive a $10 gift card to Starbucks, Chipotle, or Panera.

If you are willing to participate in this research, please contact Jonathan Engelman (see below) to set up a time and place to be interviewed in person. Please read the attached consent form prior to participation. You will be asked to sign the consent form at the time of the interview.

For additional information, please contact Jonathan Engelman at 937-395-8601 ext. 53608, or via email at jonathan.engelman@kc.edu.

Principal Investigator: Jonathan Engelman, M. A.

Kettering College, Department of Science and Mathematics

Appendix E: Recruitment Flier

Kettering College

Volunteers Needed for a Research Study: "Changing Student Conceptions of Newton's Second and Third Laws Using Interactive Video Vignettes"

- This study is open to any Kettering College Student
- The purpose of this research study is to explore your perceptions of *Interactive Video Vignettes* (IVV) during the 2015-2016 academic year
- Participation in this project will take about 45-60 minutes.
- This research will be conducted at Kettering College.
- By participating in this research, you will receive your choice of a $10 gift card to Starbucks, Chipotle, or Panera
- If you choose to participate, you will take an 11 or 15 question paper and pencil test, then be video recorded while you complete the IVV. After this, you will take the same paper and pencil test. Finally, you will be interviewed while watching a video of you completing the IVV. This interview will be audio recorded.
- For additional information, please contact Jonathan Engelman at 937-395-8601, ext. 53608, or jonathan.engelman@kc.edu

Jonathan Engelman
jonathan.engelman@kc.edu
Phone: 937-395-8601

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Appendix F: Consent Form—Physics Student

INSTITUTIONAL REVIEW BOARD at
KETTERING
HEALTH NETWORK

Consent to Participate in Research

Protocol Title

Changing Student Conceptions of Newton's Second and Third Laws Using Interactive Video Vignettes—Follow-Up Study

Principal Investigator

Jonathan Engelman

Date

July 20, 2015

Kettering Health Network IRB
Approved on: 07/28/2015
Expires on: 07/20/2016

CONSENT TO PARTICIPATE IN RESEARCH

Changing Student Conceptions of Newton's Second and Third Laws Using Interactive Video Vignettes—Follow-Up Study

Introduction

You are being asked to volunteer for this research study because you are a student in PHYS 141 (General Physics) at Kettering College. Please take your time to make your decision. Discuss it with others.

The study is being conducted at Kettering College.

The research investigator in charge of this study is Jonathan Engelman.

Your participation in the study will last approximately 15 minutes at the beginning of the semester, 15 minutes at the end of the semester, and 45-60 minutes early in the semester. You will answer 2 sets of pre-conception questions, complete an Interactive Video Vignette while being video recorded, answer 1 set of post-conception questions, answer interview questions while watching video of you completing the IVV, and then answer 1 final set of post-conception questions. This entire process will take approximately 75-90 minutes in total across three different days. The decision to participate or not participate will not negatively impact your grade.

This study is taking place at Kettering College and about 25 people are expected to take part in the study.

Purpose of This Research Study

The purpose of this research is to better understand student conceptions of Newton's Second and Third Laws while completing an Interactive Video Vignette on one of these topics.

Study Procedures and Subject Involvement

Before taking part in this research study, the study must be explained to you and you must be given the chance to ask questions. You must also sign this consent document before your participation begins. If you agree to take part in this study, you will be asked to do the following:

Day 1 (about 15 minutes)
Data Collection I: At the beginning of the semester, you will be asked twenty-six paper and pencil questions regarding Newton's Second and Third Laws. A pseudonym of your choice will be used as an identifier to connect all data collecting.

Day 2 (about 45 – 60 minutes)
Data Collection II: Prior to completing an IVV, you will be asked twenty-six paper and pencil questions regarding Newton's Second and Third Laws. Your

answers to these questions will determine which IVV you get to complete.

Data Collection III: While completing the IVV, the computer screen will be videoed. The camera will be focused on the computer screen. This video will be stored on the researcher's password protected computer.

Data Collection IV: After completing the IVV, you will be asked either eleven questions about Newton's Second Law or fifteen questions about Newton's Third Law, depending on which IVV you just completed.

Data Collection V: You will be asked a few interview questions while watching a video of you completing the IVV. This interview will be audio-recorded. This audio recording will be stored on the researcher's password protected computer.

Day 3 (about 15 minutes)

Data Collection VI: At the end of the semester, you will be asked twenty-six paper and pencil questions regarding Newton's Second and Third Laws.

Potential Risks/Discomforts

The study has the following potential risk: While it is not expected that you will be exposed to any risk, some questions may make you feel uncomfortable. You can refuse to answer any question that you don't want to answer, or end the research process whenever you like.

The treatment or procedure may involve risk(s) that are currently not known.

Possible Benefits of Taking Part In This Study

The possible benefits of taking part in this study are: increasing your knowledge of Newton's Second or Third Laws.

Costs for Taking Part in the Study

There will be no cost to you for taking part in this research study.

Payment for Taking Part in This Study

You will be awarded 5 points of extra credit each in the quiz category of PHYS 141 for participating in parts I and VI of the data collection. For participating in data collections II-V, you will receive a $10 gift card to your choice of the following: Starbucks, Chipotle, or Panera.

Confidentiality of Research Study Records

Efforts will be made to keep your personal information confidential. We cannot guarantee absolute confidentiality. Your personal information may be released if required by law. Information that would make it possible to identify you will not be included in any reports or publications of this study. Organizations that may inspect and/or copy your research records include:

Kettering Health Network IRB

Individuals identified as key personnel for this study, and any KHN department with appropriate mandatory oversight may also inspect your records.

Withdrawal of Participation by the Research Investigator in Charge

You may be taken off the research study if you do not follow the instructions of the investigator in charge or other research team members. You may also be taken off the study if you do not meet the inclusion criteria after completing the initial data collection.

Your Rights as a Research Subject

Taking part in this study is voluntary. You may stop participating at any time. Your decision not to take part in this study will not affect your grade or any benefits to which you are entitled. If you decide to stop taking part in this study, you should tell the investigator in charge.

If you have any questions about your rights as a research subject you may call the Kettering Health Network Institutional Review Board (IRB) at 937.395.8409 or the Kettering Health Office of Corporate Integrity and Ethics at 937.558.3400. ***You may also contact the IRB in writing at Kettering Medical Center, Institutional Review Board, 3535 Southern Boulevard, Kettering, Ohio 45429.***

Names of Contacts for Questions About the Study

If you have any questions or concerns about taking part in this study, or if you think you may have been injured because of the study, call Jonathan Engelman at 937-395-8601 ext. 53608 or the Institutional Review Board (IRB) at 937.395.8409.

NEW FINDINGS

If during the course of the research study significant new findings (either good or bad) develop, you will be informed of such findings and you will have the option of withdrawing from or continuing to participate in this research study.

SIGNATURES

I have read this consent document. I have had the opportunity to discuss the information contained in the document with a member of the research team and all my immediate questions have been answered. I have been told that I can ask other questions at any time. I have been told that I will be given a copy of this signed document.

SIGNATURES

I voluntarily agree to participate in this research study.

____
Subject Name (Print or Type)

____ ________ ____________
Signature of Subject Date

You will not give up any of your legal rights by signing this consent form.

Appendix G: Consent Form—Non-Physics Student

INSTITUTIONAL REVIEW BOARD at
KETTERING
HEALTH NETWORK

Consent to Participate in Research

Protocol Title

Changing Student Conceptions of Newton's Second and Third Laws Using Interactive Video Vignettes—Follow-Up Study

Principal Investigator

Jonathan Engelman

Date

September 13, 2015

CONSENT TO PARTICIPATE IN RESEARCH

Changing Student Conceptions of Newton's Second and Third Laws Using Interactive Video Vignettes—Follow-Up Study

Introduction

You are being asked to volunteer for this research study because you are a student at Kettering College. Please take your time to make your decision. Discuss it with others.

The study is being conducted at Kettering College.

The research investigator in charge of this study is Jonathan Engelman.

Your participation in the study will last approximately 45-60. You will answer either 11 or 15 pre-conception questions, complete an Interactive Video Vignette while being video recorded, answer the same set of questions a second time, then answer interview questions while watching video of you completing the IVV. The decision to participate or not participate in this research will not negatively impact your grade in any class at Kettering College.

This study is taking place at Kettering College and about 30-35 people are expected to take part in the study.

Purpose of This Research Study

The purpose of this research is to better understand student conceptions of Newton's Second and Third Laws while completing an Interactive Video Vignette on one of these topics.

Study Procedures and Subject Involvement

Before taking part in this research study, the study must be explained to you and you must be given the chance to ask questions. You must also sign this consent document before your participation begins. If you agree to take part in this study, you will be asked to do the following:

Data Collection I: Prior to completing an IVV, you will be asked 11 questions about Newton's Second Law or 15 questions about Newton's Third Law.
Data Collection II: While completing the IVV, the computer screen will be videoed. The camera will be focused on the computer screen. This video will be stored on the researcher's password protected computer.
Data Collection III: After completing the IVV, you will be asked the same questions as before.
Data Collection IV: You will be asked a few interview questions while watching a video of you completing the IVV. This interview will be audio-recorded. This audio recording will be stored on the researcher's password protected computer.

Potential Risks/Discomforts

The study has the following potential risk: While it is not expected that you will be exposed to any risk, some questions may make you feel uncomfortable. You can refuse to answer any question that you don't want to answer, or end the research process whenever you like.

The treatment or procedure may involve risk(s) that are currently not known.

Possible Benefits of Taking Part In This Study

The possible benefits of taking part in this study are: increasing your knowledge of Newton's Second or Third Laws.

Costs for Taking Part in the Study

There will be no cost to you for taking part in this research study.

Payment for Taking Part in This Study

For participating in this study, you will receive a $10 gift card to your choice of the following: Starbucks, Chipotle, or Panera.

Confidentiality of Research Study Records

Efforts will be made to keep your personal information confidential. We cannot guarantee absolute confidentiality. Your personal information may be released if required by law. Information that would make it possible to identify you will not be included in any reports or publications of this study. Organizations that may inspect and/or copy your research records include:

Kettering Health Network IRB

Individuals identified as key personnel for this study, and any KHN department with appropriate mandatory oversight may also inspect your records.

Withdrawal of Participation by the Research Investigator in Charge

You may be taken off the research study if you do not follow the instructions of the investigator in charge or other research team members. You may also be taken off the study if you do not meet the inclusion criteria after completing the initial data collection.

Your Rights as a Research Subject

Taking part in this study is voluntary. You may stop participating at any time. Your decision not to take part in this study will not affect your grade in any Kettering College course or any benefits to which you are entitled. If you decide to stop taking part in this study, you should tell the investigator in charge.

If you have any questions about your rights as a research subject you may call the Kettering Health Network Institutional Review Board (IRB) at 937.395.8409 or the Kettering Health Office of Corporate Integrity and Ethics at 937.558.3400. ***You may also contact the IRB in writing at Kettering Medical Center, Institutional Review Board, 3535 Southern Boulevard, Kettering, Ohio 45429.***

Names of Contacts for Questions About the Study

If you have any questions or concerns about taking part in this study, or if you think you may have been injured because of the study, call Jonathan Engelman at 937-395-8601 ext. 53608 or the Institutional Review Board (IRB) at 937.395.8409.

NEW FINDINGS

If during the course of the research study significant new findings (either good or bad) develop, you will be informed of such findings and you will have the option of withdrawing from or continuing to participate in this research study.

SIGNATURES

I have read this consent document. I have had the opportunity to discuss the information contained in the document with a member of the research team and all my immediate questions have been answered. I have been told that I can ask other questions at any time. I have been told that I will be given a copy of this signed document.

SIGNATURES

I voluntarily agree to participate in this research study.

____
Subject Name (Print or Type)

____ ____________________
Signature of Subject Date

You will not give up any of your legal rights by signing this consent form.

Appendix H: KHN IRB Approval Letter

INSTITUTIONAL REVIEW BOARD at KETTERING HEALTH NETWORK℠

3535 Southern Blvd.
Kettering, Ohio 45429

FWA: 00000619
IRB #:00001338

IRB APPROVAL NOTICE

DATE:	October 8, 2015
TO:	Jonathan Engelman
FROM:	Kettering Health Network Institutional Review Board
IRB REFERENCE #:	15-048
STUDY TITLE:	[778757-3] Changing Student Conceptions of Newton's Second and Third Laws Using Interactive Video Vignettes--Follow-Up Study
SUBMISSION TYPE:	Amendment/Modification
ACTION:	APPROVED
APPROVAL DATE:	October 7, 2015
EXPIRATION DATE:	July 20, 2016
REVIEW TYPE:	Expedited Review
REVIEW CATEGORY:	Expedited review categories #6 & #7

Thank you for your submission of the materials referenced above for this research study. The Kettering Health Network Institutional Review Board has approved your submission based on applicable federal regulations. All research must be conducted in accordance with this approved submission.

This project has been determined to be **Minimal Risk** and requires Continuing Review by the IRB on an annual basis.

The following materials were acknowledged and/or approved:

- Advertisement - Additional Recruitment flier (UPDATED: 09/28/2015)
- Amendment/Modification - Amendment Request (UPDATED: 09/28/2015)
- Consent Form - Additional Consent Form (UPDATED: 09/28/2015)
- Data Collection - N3 Post IVV Video Elicitation Interview Protocol (UPDATED: 09/28/2015)
- Data Collection - N2 Post IVV Video Elicitation Interview Protocol (UPDATED: 09/28/2015)
- Protocol - Protocol (UPDATED: 09/28/2015)

Please be advised the advertisement duplicates the length of participation. If you wish to modify, please submit a Revision/Amendment Request and a revised advertisement.

This approval is subject to the following:

- The informed consent process must continue throughout this study. Federal regulations require each participant receive a copy of the signed consent document.

- Any changes to the study must be promptly reported and approved prior to initiation [45 CFR 46.103(b)(4)] except when necessary to eliminate apparent immediate hazards to the subject.
- All unanticipated problems involving risks to subjects or others must be reported to the IRB within 5 working days. All requirements for reporting to the FDA and/or sponsor must also be followed.
- All deviations or issues of non-compliance must be reported to the IRB without delay.
- All research records must be retained for a minimum of three years after completion of the study.
- This protocol does not involve protected health information (PHI) and does not have HIPAA implications.

You may continue to conduct your study as approved. This approval expires on July 20, 2016, unless closed or approved for continuance before that date.

Should you have any questions or need further information, please contact Jessica Prim at 937-395-8309 or jessica.prim@khnetwork.org.

Please include any applicable forms, your study title,
and KHN IRB reference number with any submissions to this office

Appendix I: UC IRB Authorization Agreement

Institutional Review Board (IRB) Authorization Agreement

Name of Institution or Organization Providing IRB Review (Institution/Organization A):
Kettering Health Network IRB #1 (A)

IRB Registration #: IRB00001338_____ Federalwide Assurance (FWA) #, if any: FWA00000619________

Name of Institution Relying on the Designated IRB (Institution B):
University of Cincinnati

FWA #: FWA00003152

The Officials signing below agree that ***University of Cincinnati*** may rely on the designated IRB for review and continuing oversight of its human subjects research described below:

☐ Human research protocols in which one or more researchers are affiliated with both Kettering Health Network and the University of Cincinnati, for which research subjects are **not** accrued from any University of Cincinnati facilities, and for which research subjects are accrued, at least in part, from Kettering Health Network facilities.

☒ Single Research Project: *Changing Student Conceptions of Newton's Second and Third Laws Using Interactive Video Vignettes--Follow-Up Study*; Principal Investigator: Jonathan A. Engelman

The review performed by the designated IRB at Institution/Organization A will meet the human subject protection requirements of Institution B's OHRP-approved FWA, and if pertinent to the study, 21 CFR Parts 50/56. The IRB at Institution/Organization A will follow written procedures for reporting its findings and actions to appropriate officials at Institution B. Relevant minutes of IRB meetings, the application, protocol, informed consent, IRB communications and correspondence from external agencies will be made available or accessible to Institution B upon request.

Institution B remains responsible for ensuring compliance with the IRB's determinations and with the terms of its OHRP-approved FWA. Institution B is responsible for ensuring that its employees or agents conducting research subject to this agreement:

1. Remain free of any conflicts of interest per federal and state regulations or appropriately manage such conflicts,
2. Are appropriately qualified and trained to perform human research,
3. Comply with federal and state regulations and any additional requirements of funding agencies in the performance of research activities.

For research subject to this agreement that will involve Institution B's patients, employees, facilities, or premises in whole or in part, Institution B reserves the right to audit the conduct of the research and enforce Institution B's policies governing research with such components.

The terms of this agreement shall commence upon the signing of this Agreement and shall continue until terminated. Either party may terminate this Agreement upon sixty (60) days written notification to the other party. Both parties may mutually agree to terminate this Agreement at any time. This agreement shall supersede all prior agreements.

This document must be kept on file by both parties and provided to OHRP upon request.

Robert T Smith — 11/2/15

Signature of Signatory Official (Institution/Organization A) — Date
Name of Signatory Official: Robert T. Smith, M.D. — Institutional Title: Institutional Official

Jane E. Strasser — 23 October 2015

Signature of Signatory Official (Institution B) — Date
Name of Signatory Official: Jane E. Strasser — Institutional Title: Institutional Official

Signature of Other Signatory Official (Institution B) — Date
Name of Signatory Official: Click here to enter text.: — Institutional Title: Click here to enter text.

Page 1 of 2

Contact Information (Institution B)

Mailing Address: 51 Goodman Dr, Suite 300, ML 0567
City, State, Zip: Cincinnati, OH 45221-0567
Website:researchcompliance.uc.edu/hrpp/overview

Institutional Official:

Name & Degrees: Jane Strasser, PhD
Title: Office of Research Associate VP
Phone Number: 513-558-5259
e-mail: irb@ucmail.uc.edu

Human Protections Administrator:

Name & Degrees: Kareemah Mills
Title: HRPP Assistant Director
Phone Number: 513-558-3576
e-mail: millsks@ucmail.uc.edu

Appendix J: N2 Conceptions Instrument Analysis Tool

	Pre Answers	Pre Misconception	Post Answers	Post Misconception
Question 1		FALSE		FALSE
Question 2		FALSE		FALSE
Question 3		FALSE		FALSE
Question 4		FALSE		FALSE
Question 5		FALSE		FALSE
Question 6		FALSE		FALSE
Question 7		FALSE		FALSE
Question 8		FALSE		FALSE
Question 9		FALSE		FALSE
Question 10		FALSE		FALSE
Question 11		FALSE		FALSE
# Correct				
% Correct	0		0	
Hake's Gain	0			
	Interview			
	Notes			

	Answer	Misconception
Question 1	a	velocity proportional to applied force
	b	correct
	c	active force wears out
	d	force causes acceleration to terminal velocity
	e	active force wears out
Question 2	a	velocity proportional to applied force
	b	constant force means constant velocity
	c	motion when force overcomes resistance
	d	active force wears out
	e	correct
Question 3	a	velocity proportional to applied force

	b	correct
	c	active force wears out
	d	force causes acceleration to terminal velocity
Question 4	a	acceleration equals velocity
	b	acceleration equals velocity
	c	velocity proportional to applied force
	d	motion when force overcomes resistance
	e	correct
	f	
	g	
	h	
	j	none
Question 5	a	acceleration equals velocity
	b	negative acceleration equals velocity
	c	
	d	
	e	correct
	f	
	g	
	h	
	j	none
Question 6	a	correct
	b	negative acceleration instead of positive acceleration
	c	acceleration equals velocity
	d	
	e	
	f	
	g	velocity proportional to applied force
	h	
	j	
Question 7	a	acceleration equals velocity
	b	acceleration equals velocity
	c	velocity proportional to applied force
	d	
	e	correct
	f	
	g	none
	h	
	j	none

Question 8	a	positive acceleration instead of negative acceleration
	b	correct
	c	
	d	acceleration equals velocity
	e	
	f	acceleration equals velocity
	g	
	h	acceleration equals velocity
	j	
Question 9	a	positive acceleration instead of negative acceleration
	b	correct
	c	acceleration equals velocity
	d	
	e	
	f	
	g	
	h	acceleration equals velocity
	j	none
Question 10	a	
	b	
	c	
	d	
	e	
	f	acceleration equals velocity
	g	correct
	h	
	j	none
Question 11	a	
	b	acceleration equals force
	c	
	d	acceleration equals force
	e	correct
	f	
	g	active force wears out
	h	active force wears out
	j	

Appendix K: N3 Conceptions Instrument Analysis Tool

	Pre Answers	Pre Misconception	Post Answers	Post Misconception
Question 12		FALSE		FALSE
Question 13		FALSE		FALSE
Question 14		FALSE		FALSE
Question 15		FALSE		FALSE
Question 16		FALSE		FALSE
Question 17		FALSE		FALSE
Question 18		FALSE		FALSE
Question 19		FALSE		FALSE
Question 20		FALSE		FALSE
Question 21		FALSE		FALSE
Question 22		FALSE		FALSE
Question 23		FALSE		FALSE
Question 24		FALSE		FALSE
Question 25		FALSE		FALSE
Question 26		FALSE		FALSE
# Correct				
% Correct	0		0	
Hake's Gain	0			
	Interview			
	Notes			

	Answer	Misconception
Question 12	a	greater mass implies greater force
	b	collisions
	c	obstacles exert no force
	d	greater mass implies greater force
	e	correct
Question 13	a	correct
	b	greater mass implies greater force
	c	most active agent produces greatest force
	d	only active agents exert forces
	e	obstacles exert no force

Question 14	a	correct
	b	greater mass implies greater force
	c	most active agent produces greates force
	d	only active agents exert forces
	e	obstacles exert no force
Question 15	a	obstacles exert no force
	b	only active agents exert forces
	c	collisions
	d	greater mass implies greater force
	e	correct
Question 16	a	greater mass implies greater force
	b	collisions
	c	obstacles exert no force
	d	only active agents exert forces
	e	correct
Question 17	a	greater mass implies greater force
	b	
	c	
	d	greater mass implies greater force
	e	correct
	f	
	j	
Question 18	a	greater mass implies greater force
	b	most active agent produces greater force
	c	none
	d	
	e	correct
	f	
	j	
Question 19	a	greater mass implies greater force
	b	only active agents exert forces
	c	obstacles exert no force
	d	greater mass implies greater force
	e	correct
	f	
	j	none

Question 20	a	
	b	
	c	only active agents exert forces
	d	
	e	correct
	f	
	j	
Question 21	a	
	b	only active agents exert forces
	c	obstacles exert no forces
	d	greater mass implies greater force
	e	correct
	f	
	j	none
Question 22	a	correct
	b	greater mass implies greater force
	c	only active agents exert forces
	d	only active agents exert forces
	e	
	j	
Question 23	a	correct
	b	
	c	only active agents exert forces
	d	only active agents exert forces
	e	
	j	
Question 24	a	correct
	b	
	c	only active agents exert forces
	d	only active agents exert forces
	e	
	j	
Question 25	a	correct
	b	greater mass implies greater force
	c	only active agents exert forces
	d	
	e	
	j	

Question 26	a	obstacles exert no force
	b	only active agents exert forces
	c	collisions
	d	greater mass implies greater force
	e	correct
	j	