THE PROBLEM-CONTEXT DEPENDENCE OF STUDENTS' APPLICATION OF NEWTON'S SECOND LAW

By

ALICIA R. ALLBAUGH

B. S., The Ohio State University, 1988

A DISSERTATION

Submitted in partial fulfillment of the

Requirements for the degree

DOCTOR OF PHILOSOPHY

Department of Physics
College of Arts and Sciences

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2003

Approved by:

Major Professor
Dean A. Zollman

THE PROBLEM CONTEXT DEPENDENCY OF STUDENTS' APPLICATION OF NEWTON'S SECOND LAW

By

ALICIA R. ALLBAUGH

B. S., The Ohio State University, 1988

AN ABSTRACT OF A DISSERTATION

Submitted in partial fulfillment of the

Requirements for the degree

DOCTOR OF PHILOSOPHY

Department of Physics
College of Arts and Sciences

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2003

ABSTRACT

Previous research has indicated that improved knowledge organization allows experts to solve problems in a larger variety of contextual settings. In addition, it has been suggested that contextual appreciation is a form of learning ignored by much instruction. To that end, this study investigated students' understanding and application of Newton's Second Law (F=ma) in scenarios differing from those used in instruction of the concept. Instruction in these other contextual arenas, for example electrostatics, does not necessarily include Newton's laws explicitly. Instructors tacitly assumed that the student already has learned the concept fully from previous instruction on the topic.

The study used a qualitative design in a constructivist framework. Students were asked questions regarding that concept in a series of six interviews that spanned several topics in a two-semester, calculus-based introductory physics course. No student was consistent with respect to the application of Newton's Second Law throughout the entire course. However, student responses from these interviews fell into clear categories and themes emerged.

These categories revealed new contextually dependent misconceptions for Newton's second law. Additionally, student responses were clearly affected by the question contextual scenario for the following areas: Rotational Motion, Changing Mass Propulsion, Electric Charges, Electric and Magnetic Fields, Charge with Velocity.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

This dissertation was not the work of a sole individual as it might appear from the title page. Much support and collaboration was afforded.

In sincere gratitude I acknowledge:

All of the student participants: Their willingness to give of their time was foremost in making this project possible.

Dean Zollman, my advisor: He took a chance on a very stale student. I appreciate all of the guidance and insights.

Sanjay Rebello, dissertation committee member: For the many hours of discussion and at times argument. I may not have stuck it out if it weren't for his encouragement.

Alice Churukian: For the fine example.

Zdeslav Hrepic: I'm not sure I would have appreciated the English language as much without him.

Paula Engelhardt, Post Doctoral Researcher: Her arrival was at just the right time.

Kim Coy, administrator for the Physics Education Research Group: For the occasional kick in the pants.

All of the members of the Physics Education Research Group (including the Math contingent): Your comments, insights and support were appreciated.

The Galileo Flight Team at the Jet Propulsion Laboratory: Their confidence in me is overwhelming. I finished before the end of mission!

Hilary Eaton Esry and Vince Needham: True friends as well as providers of more interesting work to do.

My family: They have always been there and continue to be.

Edward Hirst, my love: For everything – infinity!

DEDICATION

I dedicate this work to my brother, Dwayne Allbaugh and Dr. Bruce Mainland, Professor of Physics at the Ohio State University, Newark Campus.

Dwayne started me along this path, oh so long ago. He convinced me to take physics in high school. "You can always drop it," he said. I never have.

Dr. Mainland taught my first college course in physics, patiently explained what X was, and befriended me along the way.

Both of these men have been great sources of encouragement and inspiration.

CHAPTER 1 – INTRODUCTION

After a topic has been covered in a course, the assumption made by many instructors is that the students understand the topic that was taught at least well enough to apply that concept during the rest of the course. This assumption shows itself in later tasks in the course that presume an understanding of the topic and in later courses where the subject matter is considered a pre-requisite to enrollment. The assumption that a student has learned the material is largely based on the student's performance on course assessment tasks. Much research has shown that just because a student has earned a passing score in a course, or even a very high score, he or she does not have a good conceptual understanding of the topics that were covered (Cohen, Hillman, & Agne, 1978; Lin, 1982; McDermott, 1991).

The 'Assumption of Transference' between topics in a given physics course is the inspiration for this study. Bagno, Eylon and Ganiel (2000, p. S17) more clearly articulate this assumption:

> "It is often assumed that the strong resemblance between several examples of a general concept is readily identified by learners. Furthermore, it is also assumed that when comparing examples of a single general concept, learners will easily differentiate between the critical attributes that characterize the general concept and the noncritical attributes unique to each example"

The overarching goal of the present study is to look at smaller steps than the end of the course grade or conceptual evaluation. This approach enables one to view student understanding from these other topic perspectives and evaluate if it holds throughout different aspects of instruction. Insight into these smaller details can help identify difficulties and improve instruction throughout the course to attain a fuller understanding by the student.

1.1 *Newton's Second Law*

Newton's Second Law relates forces on an object to its accelerated motion that is proportional to the object's mass, F=ma. This relation was chosen as the concept to follow throughout the calculus-based introductory course. This choice was governed by a number of factors:

1) It is taught early in the course, which maximizes opportunity to investigate student understanding and transfer later in the course.
2) It is a well-researched concept. Misconceptions are already classified for this topic.
3) It is referenced by many other topics taught in the course.
4) It is not a complex concept. Thus, the evaluation as to whether it was used by the student is simplified.

The calculus-based course was chosen over other introductory physics courses because it covers the largest variety of conceptual topics. Also, the topics are covered in more depth providing a richer basis to harvest data on student understanding.

1.2 *Integration with Existing Research*

The majority of physics education research in the last 25 years has focused on identifying student misconceptions concerning a particular topic. Most of these studies focused on Newton's laws in mechanics (McDermott & Redish, 1999). In addition to identifying misconceptions held by students, they have also reported them to be rather persistent. Even after thorough and innovative teaching methods, these misconceptions have remained or re-emerged (Wandersee, Mintzes, & Novak, 1994).

A large portion of these studies shared a similar research design: 1) Test students on a concept, 2) instruct students in the topics covering that concept, 3) retest students on that concept. This design is effective at determining the prevalence and persistence of student misconceptions in a particular topic. However, in general only one type of problem context or conceptual area is employed by the instrument and typically the instruction in those types of designs.

Many studies have investigated student understanding of Newton's laws in conceptual areas other than the one in which it is taught (Galili, 1995; Halloun & Hestenes, 1985; Palmer, 1997). These studies have focused primarily on Newton's first law and have reported misconceptions continuing into or emerging in these other areas. They typically did not investigate more than two differing conceptual areas.

The overarching goal of this study is to investigate the contextual dependence of student's use and/or understanding of Newton's Second Law in a diversity of task situations. This particular concept has not been studied before in other conceptual areas. In pursuing this goal, the following research questions were posed.

1.3 *Research Questions*

- *After instruction in the course, do students continue to understand and apply Newton's Second Law throughout the rest of the course topics?*

Other researchers (Galili, 1995; Rebello, Itza-Ortiz, & Zollman, 2003) have reported finding student's use of Newton's first law in other topics. This study could support their findings and extend their reach.

- *Does question context affect the student's application of Newton's Second Law?*

Discovering that students neglect to use Newton's Second Law correctly after instruction is interesting, but not enough. This main focus of the research investigation aims to find contextual scenarios that hamper student's choice in using Newton's Second Law. Moreover, the aim is to determine what factors cause the student to choose other reasoning. Accounting for these factors could improve instruction on these other topics.

From other research and the author's personal experience, electromagnetism would not be a surprising area to find student difficulty. Particle motion in electromagnetic contexts is rarely addressed in the introductory course, especially from a mechanics perspective using Newton's laws. However, rotational motion would be more surprising due to its similarity to the scenario in which Newton's laws are introduced.

- *Does a student's course performance reflect the student's use and understanding of Newton's Second Law?*

Research has confirmed that course assessment performance and conceptual understanding are not necessarily equivalent (Clement, 1982; Lin, 1982; Trowbridge & McDermott, 1981). This study is investigating whether a student uses Newton's Second Law reasoning in many situations where an expert would use it. This result reveals information on a student's use of mental models that could possibly correlate to course performance. Since some of the first semester assessment focuses on Newton's laws, some bias of conceptual understanding of Newton's Second Law towards the first semester performance is expected.

1.4 *Summary*

The assumption that a student learns Newton's Second Law well enough during instruction to employ it correctly throughout the year-long introductory course is investigated. The study follows students from instruction on Newton's laws to other topics covered in the course. The investigation probes into whether these other topics influence the student's choices with respect Newton's Second Law. Research in this area has not been performed to this depth and not on this concept. The investigation also compares Newton's Second Law use and understanding to course performance.

CHAPTER 2 – REVIEW OF LITERATURE

Constructivism is an educational philosophy or theory based on the tenet that students (and at some level all humans are students) are not merely receiving and storing information as the objectivists, traditionalists or behaviorists might argue. (Bodner & Klobuchar, 2001) But rather, students are actively involved in constructing and organizing their knowledge. In this way, constructivists have been "concerned with how the individual learner goes about the construction of knowledge in his or her own cognitive apparatus". (Phillips 1995, p. 7) Cobb (1994, p. 4) describes the differences between the constructivist and objectivist as a "dichotomy between the ideas that students construct their own knowledge and those in which it is transmitted to them". As with any philosophy, Constructivism has many perspectives from which to interpret it. Phillips (1995) describes these different views as akin to sects within "a secular religion". But however divided these perspectives, they all have the focus on the individual learner versus learning as a public discipline.

2.1 *Social Constructivism and Radical Constructivism*

According to von Glasersfeld (1995), constructivist epistemology dates back thousands of years to Xenophanes who lived in the 6th century BC. The notion of students constructing individual knowledge is attributed to Vico over a thousand years later (Glasersfeld, 1988). However its basis was contemplated, constructivism was not adopted until the 20th century AD when Piaget published his *Genetic Epistemology* (Piaget, 1970). Not too much later, Vygotsky (1986) joined the ranks. Widely recognized as forefathers of constructivism, Piaget and Vygotsky are probably the best known constructivists. However, they differ quite a bit in their perspectives on how an individual constructs knowledge.

Social constructivism is based on work by Vygotsky and focuses on the social factors that influence individual learning. Vygotsky felt that other constructivist theories, such as Piaget's, "reduce complex superior psychic processes to natural processes and disregard the specific characteristics of the cultural development of behavior." (Vygotsky, 1930/1985 as quoted in Vérillon 2000, p. 6) "Learning does not take place in cognitive isolation, but within the context of activities and social interaction." (Vygotsky; 1986 as quoted in Meacham 2001, p. 2) Current social constructivists discuss the 'interplay among the various factors of personal experience, language, and socialization in the process of learning science in classrooms"(Driver, Asoko et al. 1994, p. 5). The investigation presented in this volume is focusing on individual understanding within an introductory physics course. These overarching social factors are beyond the scope of the study. Thus, a more radical cognitive constructivism framework was adopted.

Cognitive constructivism based on the work of Piaget focuses on biological and psychological mechanisms within the individual learner. His idea was that as children grow they pass from simple to complex stages of thought. This progression is natural and biologically based. In his theory, the final step is from concrete operations to formal operations. Piaget stated that the transition from concrete to formal operations occurred in the early teens. McKinnon and Renner (1971) found that both of these last two stages were also found in the reasoning of college students.

In moving from one stage to the next, a process of assimilation and accommodation occurs. The old ideas must be modified to accommodate the new information which is assimilated into the old. This describes a process of learning. Learning in this or similar manner has been generally termed 'Conceptual Change' emphasizing the constructivist basis that the student has conceptions to change rather than the behaviorists ideas that the student merely receives the concept from the instructor.

Built on the work of Piaget, radical constructivism as practiced by von Glasersfeld (1988) considers the construction of knowledge as "adaptive and the character of cognition as functional" (Staver 1998, p.504). The learner builds "new understanding…on the basis of previously constructed mental schemes" (Derry 1996, p. 165). The radical difference is that the conceptual change occurs not because of natural biological development, but due to the individual's reflective activity.

2.2 *Mental Models*

Redish (1994) defines mental models as the cognitive patterns that people construct. He goes on to assert in a constructivist manner that people tend to organize their experiences and observations into these mental models. The term 'mental model' is used by many researchers (See Gentner and Stevens 1983, for example). Greca and Moreira (2002, p.108) define a mental model in this manner:

"A mental model is an internal representation which acts out as a structural analogue of situations or processes. Its role is to account for the individual's reasoning both when they try to understand discourse and when they try to explain and predict the physical world behavior."

Additionally, mental models have these characteristics (Norman, 1983; Redish, 1994):

1) They consist of propositions, images, rules of procedure and statements as to when and how they are to be used.
2) They are incomplete.
3) They may contain contradictory elements.
4) They are unstable: People may not know how to 'run' the procedures in their mental models.
5) They do not have firm boundaries – similar elements in the model may get confused.
6) Mental models tend to minimize expenditure of mental energy. People will often do extra physical activities to reduce mental complexity.

These characteristics and definitions imply some amount of structure. The detailed structure of these mental constructs has been discussed in other research (deJong & Ferguson-Hessler, 1996; diSessa, 2002; Hammer, 2000; Minstrell, 1992). However, the definition provided by Greca and Moreira suffices for this investigation. Since Newton's Second Law is a fairly straight forward concept with few confounding factors, the student's use of it as a mental construct should be determinable to the level described in the above definition.

2.3 *Conceptual Change*

As mentioned earlier, the process of learning is deemed conceptual change from the constructivist perspective. Many theories exist to explain how this change occurs based on the theorist's particular view of knowledge structure. The theories of conceptual change differ in terms of the grain size of information that is processed: The smallest pieces of knowledge are re-organized (Smith & diSessa, 1993); Parts of concepts are modified and/or built upon (Piaget, 1970); Whole concepts are replaced (Chi & roscoe, 2002)or re-categorized (Chi, Slotta, & Leeuw, 1994). None of the referenced researchers addressed context in their theories of conceptual change. To address this, an additional dimension for mental constructs to conceptual change has been proposed:

> "Clearly the appropriate application of scientific theories and concepts requires an appreciation of context – forging an appropriate relationship with the context. Consequently it would seem reasonable to argue that it is inadequate to depict meaningful learning in terms of a changing of conceptions in the sense of simply generating a new or altered cognitive structure." (Linder 1993, p 5)

> "Instead of depicting meaningful learning in terms of conceptual *change* we should consider depicting it in terms of conceptual *appreciation* – an appreciation that is *delimited by context*." (Linder 1993, p 295 original emphasis)

This notion is supported by Vosniadou (1999) in her view towards future directions for conceptual change theory. She states that "knowledge acquisition process may be different in different subject matter areas" (Vosniadou, 1999, p. 12). Mortimer (1995) lends support as well from a social constructivist perspective taking environmental settings as ‘scientific’ or ‘everyday’ as contexts. Halldén (1999) includes these ideas of contextual appreciation in her definitions of contextualizations which include task context and environments. Studies on problems solving in physics (Chi, Feltovich, & Glaser, 1981; Larkin, McDermott, Simon, & Simon, 1980) indicate knowledge organization as “one of the factors in the preeminence of the expert over the novice. Such organization facilitates transfer between different domains and helps in dealing with novel situations.” (Bagno, Eylon et al. 2000, p S16). Contextual appreciation could be a factor in determining the stage of understanding: Novice to expert or concrete operations to formal operations. Determining when this contextual appreciation occurs (or does not as the case may be) is the focus of this study.

2.4 *Context*

The term context possesses many different meanings depending on the, ahem, context of its use. Its coverage spans from the overall social culture to the wording in an arithmetic problem. Table 2.4 lists many of the meanings of the term and the different researchers who have given it that meaning.

Table 2.4 Different Uses of Context

Meaning of Context	**Researchers**
Overall Social Culture	(Atwater, Alick, Foley, Kight, & Smith, 1994; Cobern, 1993; Wiggins, 1993)
Institutional Culture	(Klaczynski, 1994; Munby & Russell, 1998)
Subject Areas/Disciplines	(Arzi, 1985; Perkins & Salomon, 1998)
Classroom Setting	(Choi & Song, 1996; Erickson, 1994)
Problem Content Area	(Engel Clough & Driver, 1986; Galili, 1995; Rebello et al., 2003; Törnkvist, Pettersson, & Tranströmer, 1993)
Problem Setting	(Engel Clough & Driver, 1986; Halldén, 1990; Medin & Shoben, 1988; Millar & Kragh, 1994; Palmer, 1997; Pozo, Gomez, & Sanz, 1999; Rennie & Parker, 1996)
Problem Situation	(Bao, Hogg, & Zollman, 2002; Palmer, 1997; Zollman, 1987)
Problem Order	(Brennan, 1992; Leary & Dorans, 1985)
Problem Wording/Form	(Cummins, Kintsch, Reusser, & Weimer, 1988; De Corte, 1985; Fan, Mueller, & Marini, 1994; LeBlanc, 1994; Rebello, 2003; Reusser, 1990; Zollman, 1987)

The differences between problem setting and problem situation as listed in Table 2.4 are subtle. An example of problem setting change is an everyday versus scientific setting for identical action in a problem. But, a difference in problem situation is noted by a vertical versus horizontal orientation for an action. This new situation changes the alignment with gravity and thus the solution to the problem.

Similarly, the term ‘domain’ has also been used for many of the larger scope uses of ‘context’ listed in Table 2.4. The ambiguity begs clarification.

2.4.1 *Definitions for this Study*

The investigation at hand focuses on concepts used in homework tasks covered in an introductory course. Context only needs to be clarified for problems and therefore not include the scope of classroom, institution or overall social cultures. Also, the investigation is not changing the order or wording of the probe questions. Others at Kansas State University (Engelhardt & Rebello, 2003; Gray, Rebello, & Zollman, 2003) are investigating question order effects on both exams and in interviews. Those aspects are not addressed here.

A hierarchy of problem or task classification is defined for this study: Domain, Context, Scenario, and Feature. This hierarchy is from the general to the specific. See Table 2.4.1 for definitions and examples.

Table 2.4.1 Classification of Problem Context

Term	**Definition**	**Example**
Domain	An overarching theme of concepts.	Mechanics, Oscillations, Electromagnetism.
Context	A specific area of the concept domain.	Electromagnetism has several contexts: Electrical Charges; Electric Fields; Magnetic Fields; Magnetic Poles;
Scenario	The specific situation within a context. A description of what is happening in the task.	Electric charges are moving, fixed, released from rest, etc.
Feature	Objects that make up the scenario or characteristics of them.	The charge is positive or negative. The amount of charge, amount of mass. Number of charges, etc.

In all of the above-mentioned studies, the work of Engel Clough and Driver (1986) is the only one that investigated consistency of student responses across more than two domains (as defined here). Palmer (1997) and Zollman (1987) investigated only scenario changes.

Bao, Hogg, and Zollman (2002) and Rebello, Itza-Ortiz and Zollman (2003) used responses to certain feature changes by students to determine their mental models for the given context. Similarly, this investigation will vary all of these parameters to some extent and study the contextual dependence of student mental models of Newton's Second Law. An overview of the research in the investigated domains follows.

2.4.2 *Mechanics*

The conceptual area of mechanics is by far the most thoroughly researched topic in physics education. In 1994 Wandersee, Mintzes and Novak reported (1994, p. 181):

> "Of some 700 studies within the school subject of physics about 300 have been devoted to concepts in mechanics (including force and motion, gravity, velocity and acceleration), about 159 to electricity, and about 70 each to concepts of heat, optics and the particulate nature of matter and energy. The earth and space sciences have sparked some 35 studies and 'modern physics' (physics based on relativity and quantum theory) about 10."

In a Resource Letter on Physics Education Research, McDermott and Redish (1999) list 55 references for mechanics (linear forces, kinematics, and uniform circular motion) of the total of 115 references for all physics domains.

This focus on mechanics is somewhat understandable. Above all, mechanics is taught at all levels of education providing both opportunity for research and an audience for its outcomes. Mechanics is the area where students have the most obvious and explicit personal experience and therefore have formed their own concepts before entering the classroom.

From a constructivist point of view, mechanics forms the basis on which all other physics understanding is built placing it in a crucial foundational stance. This notion is best articulated by Galili (1995, p. 371):

"The importance of mechanics is more than just being one of these domains. It determines the 'rules of the game', defines the main tools in physics, presents the most universal laws of nature. It actually describes the method of the discipline of physics which is then applied in all other domains in this discipline."

2.4.2.1 *Misconceptions*

Much of the research in this and other content areas has been on the pre-existing mental models that a student brings to the classroom (Clement, 1982; Halloun & Hestenes, 1985; McDermott, 1983; McDermott, 1984; McDermott & Redish, 1999; Wandersee et al., 1994). These mental models have been called preconceptions, alternative conceptions, common sense concepts and misconceptions (Eryilmaz, 2002). Most studies have shown that people of all ages hold some type of misconception (McCloskey, 1983a). And, students at all achievement levels have these misconceptions as well (Peters, 1982; Steinberg, Brown, & Clement, 1990). Many of these studies

(Champagne, Klopfer, & Anderson, 1980; Finegold & Gorskey, 1991; Galili & Bar, 1992; Whitaker, 1983) have discovered student reasoning similar to famous historical theories such as the impetus theory of the middle-ages and Aristotle's theories of motion. Familiarity with these theories will facilitate analysis of student responses in this study.

2.4.2.1.1 *Aristotelian Physics*

Aristotle's (384-322 BC) theory of motion included three types of motion but only two of them are significant for physics. The first is 'natural' motion which occurs due to the intrinsic influences of the properties of the body itself. Bodies move to their natural state of rest. Objects made of the heavy elements, earth and water, move downward towards the center of the universe while objects made of light elements like smoke and fire moved naturally upward. The second type of motion, 'violent' motion, was caused by an external influence. (Kearney, 2002) This external influence could be another object or a medium such as air.

Since the natural force of an object could not be changed, only the external forces could change and alter an objects motion from its natural tendency. As the external force increases so does the <u>speed</u> of the motion. (Ebison, 1993) This conclusion of Aristotle is the basis for using the equation F=mv to label Aristotelian reasoning in research such as that by Rebello, Izta-Ortiz and Zollman (2003). However, the mass correlation is not truly Aristotelian and should be used with caution

According to Aristotle, to be maintained all motion required either an internal or external force. It was motion that had to be explained because rest was the natural state.

(Ebison, 1993) This conclusion is the basis for the 'motion implies force' misconception noted by McCloskey (1983) and Galili and Bar (1992).

2.4.2.1.2 *Impetus Theory*

John Buridan (1300-1358) is often considered the founder of medieval impetus theory although several others prior to him expounded ideas with some similarities (McCloskey, 1983a). Buridan defined the "imprinting from a body onto a moved (projectile)" as impetus, "a permanent quality which is acquired and possessed by any moving body" (Giannetto 1993, p. 232-233).

This impetus also maintained a type of constancy of state: "this also included the concept of 'circular impetus' where an object moving in a circle can retain a tendency to move in a circle even when the original centripetal force is removed." (Kearney 2002, p. 56) This 'memory' of state is found in the misconceptions used in the development of evaluative instruments (Hestenes, Wells, & Swackhamer, 1992) in addressing motion of an object leaving a circular track.

2.4.2.2 *Evaluative Instruments*

As an aid in evaluating student mental models with regard to mechanics, several surveys or instruments were created. Built upon experience in creating the Mechanics Baseline Test, Hestenes, Wells and Swackhamer (1992) created the Force Concept Inventory. This inventory has become quite likely the most famous instrument in physics education research. Rebello, Itza-Ortiz and Zollman (2003) used questions from the

Force Concept Inventory as a starting point in their research because of its widespread use and familiarity within the research community. This instrument has also been the focus of much debate and discussion (Huffman, 1995; Rebello et al., 2003). Thornton and Sokoloff (1998) created the Force and Motion Conceptual Evaluation in response to some of these critiques.

Both of these tools and other methods for investigating student understanding of mechanics focus on only the contexts in which mechanics was taught. These instruments are employed in a pre-test, instruct, and then post-test sequence. Hake (1998) evaluated scores on the Force Concept Inventory from 6,000 students that were acquired in just this manner. However successful it may be in determining the prevalence of misconceptions, this method limits the research which uses it to a narrow range of contexts, scenarios and features.

In addition to finding misconceptions, these tools and methods have revealed misconceptions to be rather resistant to alteration. All the above mentioned studies found misconceptions persisting after instruction to some degree. Notably, diSessa (1982) reported a case study of a freshman student at the Massachusetts Institute of Technology who possessed these misconceptions after both high school and college instruction in mechanics. Wandersee, Mintzes and Novak (1994) report on this and several other surprising instances of persistent misconceptions. The findings reporting the persistence of misconceptions alone is enough to question the assumptions of instructors previously mentioned.

2.4.2.3 *Research Connecting Differing Mechanics Contexts*

Other researchers have applied different mechanical contexts to Newtonian problems. Halloun and Hestenes (1985) found some inconsistencies in student reasoning between linear and projectile motion scenarios. Galili and Bar (1992) discovered that students were more likely to use alternative mental models as the questions increased in difficulty from constant velocity to changing acceleration. Palmer (1997) investigated linear motion in several scenarios with different features. He found different features to be a factor in students using non-Newtonian mental models: speed of the moving object or weight of the object. He also found a difference in scenario to be a factor: e.g. direction of the motion (vertical or horizontal).

None of the above research left the mechanics domain when varying contexts. The investigation described herein is crossing several domains, contexts, scenarios and features. Previous researchers also focused more generally on Newtonian reasoning which investigated Newton's first law only.

This plethora of research in the mechanics domain was a major reason for the choice of Newton's Second Law as the topic of investigation in this study. Misconceptions or alternative mental models have been well documented and researched. Identifying student mental models regarding Newton's Second Law in various contexts is clearly viable.

2.4.3 *Rotation and Torque*

This conceptual area is associated with the mechanics domain by some practitioners in the field of physics. However, rotation and torque have been largely neglected in the research regarding the learning of mechanics. Neither of the prominent instruments for evaluating conceptual understanding of force and motion, the Force Concept Inventory and the Force and Motion Conceptual Evaluation, includes a single question regarding torque or rotation. These instruments do include concepts for motion along a curved path but not torque. For these reasons, torque and rotation are considered a separate domain in this study.

Little research which investigated torque in particular has been carried out. Barowy and Lockheed (1980) found student difficulties regarding torque. Ortiz (2001) found student misconceptions as well. Both of these studies had the student applying Newton's laws in one context only. Contextual dependency of Newtonian reasoning was not determined.

Perhaps this domain is where the assumption of transference is the most prominent. Textbooks even allude to it:

> "This formulation [$\Sigma\Gamma=I\alpha$] exhibits a very close parallel to the relation $\Sigma F=ma$ for a point mass." (Sears, Zemansky et al. 1983, p. 190, Brackets added)

> "This term is analogous to Newton's Second Law." (Fishbane, Gasiorowicz et al. 1996, p 248)

> "Here we have Newton's law, F=ma, written in terms of rotational quantities". (Wolfson and Pasachoff 1995, p 281)

And, Halliday, Resnick and Walker (2001, p. 230) refer to the section as "Newton's Second Law for Rotation". The tacit assumption is that if a student has attained Newtonian reasoning in the linear context, she or he will transfer that knowledge to the rotational context quite easily.

2.4.4 *Simple Harmonic Motion*

Simple Harmonic Motion is also a relatively neglected topic as far as research in learning is concerned. Saul (1998) studied student expectations of learning in a physics course. By evaluating specialized exam problems and student interviews, he found that interactive engagement curricula were more effective than traditional instruction for learning simple harmonic motion. Other research (Bone, 1983) used one context of simple harmonic motion in evaluating students' effective use of scientific calculators. Finegold and Gorskey (1991) had periodic motion of a pendulum as a context to study student's understanding of Newton's first law.

None of these or others that were found sought Newtonian mental models specifically in their applications. Simple harmonic motion was used as a scenario in which to pursue a separate research goal.

2.4.5 *Electromagnetism*

Some of the research in this area uses the context of electric fields or electrostatics to investigate knowledge structures and/or problem solving strategies (Ferguson-Hessler

& Jong, 1987; Savelsbergh, Jong, & Ferguson-Hessler, 2002). This perspective employs electromagnetic topics in exploring cognitive science research questions. Greca and Moreira (1997) sought student understanding of field theory. They reported that students use definitions and formulae which they manipulate routinely in order to solve problems showing poor knowledge organization These results did not differ greatly from the findings of McMillan and Swadener (1991) who reported that students did not employ qualitative thinking in this domain. Maloney (1985) discovered that students have the idea that magnetic poles are charged and therefore cause particle motion like electric charges.

2.4.5.1 *Research Connecting Electromagnetism and Other Contexts*

These types of investigations describe student knowledge with respect to electromagnetic concepts, but do not address cross-topic themes or connections. Rebello, Itza-Ortiz and Zollman (2003) reported non-Newtonian student mental models of motion were used to describe particles moving in electric fields. Törnkvist, Pettersson, and Tranströmer (1993) suggest student difficulties with field concepts and particle motion are from confusion of representations between field lines arrows, velocity arrows, and acceleration/force arrows. Where Galili (1995) viewed results in the electric field context from another perspective: "It appears problematic for students to include the concept 'field' in the mechanics framework previously acquired in physics courses (p. 382)." The referenced framework was Newton's third law and energy-work relations.

To address these cross-topic issues, Bagno, Eylon and Ganiel (2000) created an instructional method to integrate the concepts of vector field and potential in both the mechanics and electromagnetism domains of physics. Students improved their abilities to identify critical attributes of the general concepts after instruction and their abilities to analyze unfamiliar cases. More generally, Burkhardt (1987) suggested a systematic approach of instruction not only between these domains but several others as well.

The research of Rebello, Itza-Ortiz and Zollman (2003) most closely follows this investigation. They investigated student mental models in both mechanics contexts and electromagnetic contexts. Their study probed Newton's first and third laws. The interview protocols and research instruments employed changed contextual features that created changes in force but did not change the mass feature which is key in investigating Newton's Second Law. Their results showed that students did use non-Newtonian reasoning when asked about object motion in electromagnetism. However, the design of the study was not thorough enough to find which particular scenarios or features within the domain caused students to revert to these non-Newtonian mental models.

2.5 *Summary*

Radical constructivism is established as the framework for the investigation. This is built on the Piagetian premise that individuals construct their own knowledge. Those constructs are deemed mental models for the purposes of the study. Previous research into Newtonian mechanics has established prevalent misconceptions with respect to Newton's laws in students' mental models. The previous research reported reasoning much like Aristotle and the medieval impetus theory. Much of the research has been of a pre-test, instruct, post-test nature with little attention paid to context. For clarity, a hierarchy of problem context categorization was established. Other researchers have varied some of these categories in investigating Newton’s first law. The investigation described here will vary each of these categories in an attempt to determine any sensitivity of student mental models of Newton’s Second Law to these contextual categories.

CHAPTER 3 – RESEARCH DESIGN

Research project can have two basic approaches: quantitative approach or qualitative approach. Most of physics research is quantitative: for example, investigating the probability that an electron in the hydrogen atom were to change from one energy level to another by the absorption of a photon with a certain frequency. Similarly in physics education, researchers attempt to determine the probabilities of certain learning events and their causes and/or effects. However, this similarity can only go so far. Part of the reason is that students (and humans in general) do not behave as predictably as electrons. If asked the same question several times, a student may not answer the same way repeatedly and at any time may change the answer. Electrons do not have this luxury. Thus, additional methods must be employed to probe this most unwieldy of areas – the mind of a physics student.

The intent of the investigation was to investigate how Newton's Second Law is or is not used and/or understood in as many content contextual areas as possible. Qualitative methods provide the highest resolution of data for such an endeavor.

3.1 *Qualitative Methods*

The investigative procedures used for this study are generally termed qualitative methods. Bogdan, et. al (1975; 1998) describe this area generally as phenomenology. "The phenomenologist is concerned with understanding human behavior from the actor's own frame of reference instead of facts or causes of the phenomenon." In more general terms, qualitative methods produce descriptive data as compared to quantitative numerical and statistical data. The descriptions are provided by the participants themselves. Creswell (2002) further defines the difference between these quantitative and qualitative methods by what each method is trying to determine at each step of the research process. Figure 3.1 is a reproduction of Creswell's comparisons as to aid the reader.

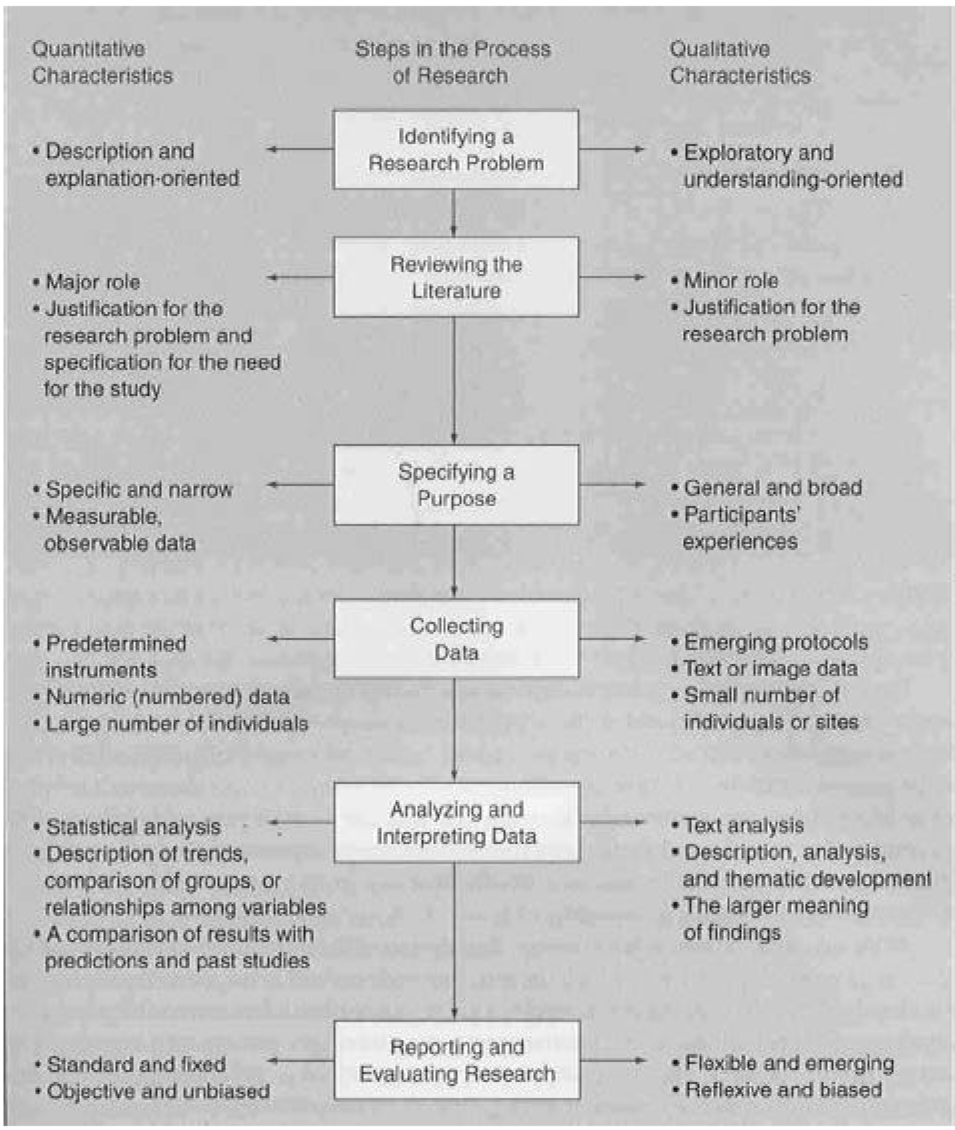


Figure 3.1 Creswell's Characteristics of Quantitative and Qualitative Research in the Process of Research (Creswell, 2002)

3.1.1 *Phenomenological Research Method*

Following the ideology of Kuhn (1970), Jacob (1987) discusses qualitative research as being practiced in several scholarly traditions. Lancy (1993) asserts that this is because many practicing qualitative researchers learned their “craft” by studying under a recognized “master”. Historically, this assertion may be so, but with the ‘recent’ growth in popularity of qualitative research, it is not necessarily true to form.

Creswell (1998) has continued with the traditions terminology. He considers the term phenomenology as more specific than Bogdan. He treats phenomenological research as one of five “qualitative traditions” rather than an overarching general term. Creswell’s five traditions are summarized in Table 3.1.1.

Table 3.1.1 Creswell's Comparisons of Five Research Traditions

Dimension	Biography	Phenomenology	Grounded Theory	Ethnography	Case Study
Focus	Exploring the life of an individual	Understanding the essence of experiences about a phenomenon	Developing a theory grounded in data from the field	Describing and interpreting a cultural and social group	Developing an in-depth analysis of a single case or multiple cases
Discipline Origin	Anthropology Literature History Psychology Sociology	Philosophy Sociology Psychology	Sociology	Cultural Anthropology	Political Science Sociology Urban Studies
Data Collection	Primarily interviews and documents	Long interviews with up to 10 people	Interviews with 20-30 individuals to "saturate" categories and detail a theory	Primarily observations and interviews with additional artifacts during extended time in the field (e.g., 6 months to a year)	Multiple sources – documents, archival records, interviews, observations, physical artifacts
Data Analysis	Stories Epiphanies Historical content	Statements Meanings Meaning themes General description of the experience	Open coding Axial coding Selective coding Conditional matrix	Description Analysis Interpretation	Description Themes Assertions
Narrative Form	Detailed picture of an individual's life	Description of the "essence" of the experience	Theory or theoretical model	Description of the cultural behavior of a group or an individual	In depth study of a "case" or "cases"

Upon examination of Table 3.1.1, one can easily determine that a biography was not appropriate for this investigation. And though the physics community and its classrooms are in ways a culture unto itself, this culture was not being investigated, so ethnography was not an appropriate approach either. One could argue that a case study would be appropriate. But, due to the exploratory nature of the investigation and its need for as much transferability to the rest of the student population as possible, much more than one case would be required and multiple sources of information were not available. Phenomenology and grounded theory are left. Because of its larger number requirements, the grounded theory approach could not be attempted. Even if the volunteer participant numbers had started that high, attrition throughout the process would have kept that option from being viable. So given the resource limitations, phenomenology was appropriate.

3.2 *Interviews*

With phenomenology as the chosen path, interviewing is the method of data collection. Two essential components are common to all types of interviews (Merton, Fiske et al. 1990, p.11):

1. The substantial part of the conversation consists of questions and answers.
2. The participants have defined, non-overlapping roles; one person asks the question (the interviewer) and the other answers the questions (the respondent).

Creswell suggests a long interview. McCracken (1988, p. 11) describes the long interview as a way to "capture the data needed for penetrating qualitative analysis without participant observation, unobtrusive observation, or prolonged contact." Since the research questions pertain only to Newton's Second Law in student responses to questions, one can also say that the interviews should be focused per the definition of Merton, Fisk and Kendall (1990). That is, the persons interviewed are known to have been involved in a particular situation and an interview guide regarding that situation can be developed. According to Krathwohl (1998), interviews can be placed upon a continuum of structure – unstructured, partially structured, semi-structured, structured, and totally structured. Given the nature of the research questions, the focus and the interview guide, semi-structured interviews with a developed and ordered interview guide, referred heretofore as the protocol, was deemed the best option for data collection. In addition, the investigation is to cover several content or contextual areas so a series of interviews was planned. Ideally, the same student would be interviewed a number of times throughout a physics course.

3.2.1 *Participant Selection*

At Kansas State University, several types of physics courses are offered – conceptually based, algebra-based, and calculus-based. Of these, the calculus based-physics course covers the widest range of content areas including electric and magnetic fields. From this course, volunteers were sought originally from one studio section to minimize the variance in the shared experience of the interviewees. As time progressed, the number of interviewees dwindled, and so more volunteers were sought from addition studio sections. Payment was offered as an incentive for participation.

3.2.2 *Participant Description*

Overall 22 students participated. Each student was interviewed from one to six times. The frequency of interviewing is listed in Table 3.2.2.

Table 3.2.2 Participants Interview Frequency

Student Number	**Interview 1**	**Interview 2**	**Interview 3**	**Interview 4**	**Interview 5**	**Interview 6**	**Total Interviews**
1	1	1	1	1	1	1	6
2	1	1	1	1	1	1	6
3	1	1	1	1			4
4	1	1	1	1			4
5	1	1	1	1			4
6	1	1	1	1			4
7	1	1	1	1	1	1	6
8	1		1	1			3
9			1	1	1	1	4
10			1	1			2
11			1	1			2
12			1	1	1	1	4
13			1				1
14			1	1	1	1	4
15			1	1	1	1	4
16					1	1	2
17					1	1	2
18					1	1	2
19					1	1	2
20					1	1	2
21					1	1	2
22	1						1
Participants per Interview	9	7	15	14	13	13	

Demographically, 14 participants are male and 8 female. Four were physics majors while the remaining 18 were engineering majors (in eight different areas). Two participants did not take the first semester course at the time of the interviews. Overall performance levels varied for the first semester interviews and understandably varied less for the second semester interviews due to its requirement of passing the first course.

3.2.3 *Timeline of Interviews*

Once a syllabus was available from the instructor, a schedule for the interviews could be set so that it that did not interfere with course exams and holidays and focused on the homework assignments of interest. Six interviews were scheduled throughout the two-semester course. Interviews 1 through 4 were approximately 30 minutes in duration and were scheduled during the first semester of the course. Interviews 5 and 6 were approximately 60 minutes in duration and were scheduled during the second semester of the course.

3.3 *Interview Protocols*

Semi-Structured Focused Interviews require a predetermined set of questions that are asked in the same order for each participant's interview. This interview protocol is the determining factor in what can and cannot be analyzed later. "What the investigator does not capture…will be lost forever" (McCracken 1988, p. 38).

The protocols utilized the assigned homework problems to narrow the range of possibilities as well as ensuring the students would have some familiarity with the concepts involved. This restriction of range to the assigned homework problems also ensured the interview would meet the criteria of a focused interview mentioned in Section 3.2. Despite this restriction, the interview protocols were designed to target as many contextual categories as possible. All of the interview protocols are included in Appendix A.

The scheduling of the interviews was determined both by avoiding exams and holidays as well as ensuring that enough of the content that concerned forces of some nature had been covered since the previous interview. The first interview was scheduled during the introductory instruction of Newton's Laws. This interview was designed to get the participant familiar with the interview technique and procedure and gather some non-course background information. Initially, students were asked to compare pairs of assigned homework problems. After the first interview, this approach revealed its weaknesses in revealing student understanding. In following suggestions in Bogdan and Bilken (1998) regarding lessons learned during data collection, the subsequent protocols were adjusted to include more conceptual questions.

3.3.1 *Conceptual Questions*

Starting with the second interview, conceptual questions that were not from the textbook were included in the interview protocols. This process had several advantages. First of all, the student obtained no cues from surrounding problems and headers in the textbook. During the early interviews, a couple of participants answered that it must have something to do with X because X is in the problem group header. Secondly, recall or reconstruction was not an issue. At times, a participant mentioned that he or she was trying to remember how the instructor in studio did the problem rather than how he or she approached it. Upon further exploration, the participant's first approach was discovered but that approach may have been tainted by the "correct" explanation that the student was trying to recall. And thirdly, several participants admitted to not attempting the homework problem that was under investigation.

The conceptual questions were always based upon concepts that were related to an assigned homework problem. Each problem scenario had a series of questions associated with it. As defined in chapter two, a scenario is the specific situation within a context, what is happening. Each question in the series had changed a feature in the scenario and asked the student to compare the result to the first question. The following is an example from Interview 3. The scenario of applying a constant force to a wrench clamped to a well greased pin was presented to the student as Figure 3.3.1.a.

Figure 3.3.1.a Wrench Scenario Image – Question 1

The student was asked to describe what would happen. That description was probed for clarity with follow up questions. Subsequently, the force was doubled in the second question. See Figure 3.3.1.b

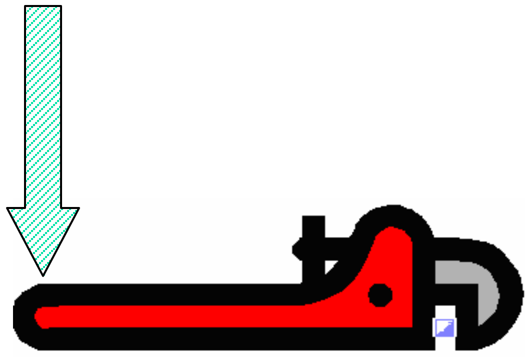


Figure 3.3.1.b Wrench Scenario Image – Question 2

This question was included to confirm the students understanding of the situation. Then the third question was posed where the original force placement was changed. See Figure 3.3.1.c.

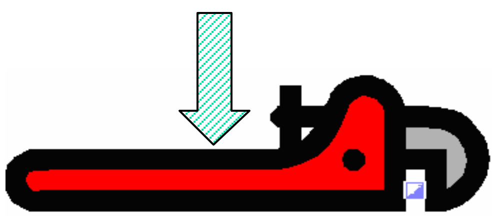


Figure 3.3.1.c Wrench Scenario Image – Question 3

In interviews 3 and 5, the probing of these conceptual questions was extended to investigate if the student could or would transfer the conceptual knowledge from the presented problem situation to a problem situation from previous experience.

3.3.2 *Maintaining Focus*

The interviews covered several interesting content contextual areas. Each of these has its misconceptions. The focus of the interviews was the concepts required to do the assigned homework problems and Newton's Second Law. At times, forgoing information regarding the content misconceptions and/or depth to remain on the path of investigating Newton's Second Law was necessary. For example, in Interview 5, the content area was electric fields. Whether or not the participant applies electric field theory has little applicability to this investigation. Asking follow up questions regarding field theory was tempting, but would not have been fruitful for this investigation. In addition, the participants are not to be dismissed either. If all of the interview questions had been strictly about force, mass and acceleration, they would have figured that out as well. To combat this impediment to validity, the interviews included questions that were not directly related to Newton's Second Law. These have been deemed distracter questions due to their intent to distract the participant from the true agenda of the interviews.

3.4 *Data Acquisition and Quality*

A single researcher conducted all of the interviews which were recorded on audiotape. Additional notes were taken on a copy of the interview protocol. The interviewer transcribed each interview. However, discussions that did not pertain to physics in any way were not transcribed. When questions arose during analysis, the interview tapes were consulted directly.

3.4.1 *Participant Sample*

Participant sampling was limited to students who had volunteered. This method is deemed "convenience" sampling (Patton, 1990; Seidman, 1998). However, the participants had varied interests and varied performance levels in the course. Both genders were adequately represented. This range of participants was similar to the larger population and was more akin to "maximum variation" sampling (Patton, 1990; Seidman, 1998). Such a sample allows for the most probable transferability to other populations.

Additionally, the student participant final course scores were compared statistically to determine if the student participants were representative of the class as a whole with respect to the course performance variable. The student course scores were separated into 10 point bins and normalized. A Chi-Squared goodness-of-fit test calculated a χ^2 value of 25.3 for the first semester and a 94.5 for the second semester. Both of these values are well above the critical value of 9.488. The student participant scores were not representative of the population of students enrolled in the course.

The average score in the first semester course was 77.2 while the student participant average was 81.0. In the second semester, the course average was 64.8 where the participant average was 83.3. The student participants were better performers than their peers on average especially in the second semester. Any misapplication of mental models would be even less likely in this group of students as compared to rest of the students enrolled in the course.

3.4.2 *Ethical Considerations*

The study was approved by the Institutional Review Board for research on human subjects prior to any of the interviews. Each participant was informed of the nature of the research and signed an informed consent form at the beginning of each semester's round of interviews – see Appendix B. A copy of the form was also given to each participant. In addition to the informed consent, an opportunity was offered and time allotted for each participant to ask questions at the end of the interviewer's set of questions. No limits were set for these questions, and typically, the students asked about the content of the interview. This process alleviated participant stress and also helped them since they were in the midst of a course where grades were to be assigned. By addressing student's deficiencies related to the content, error may have been introduced error into later data collected. However, the ethics of diagnosing a problem and then not treating it was considered of greater neglect.

3.4.3 *Possible Bias*

This "tutoring" was part of the benefit of being a participant. However, it was also a possible source of bias on the part of the students. Once they had been "tutored" on Newton's Second Law in one content contextual area, then the probability of increasing their understanding of Newton's Second Law from participation in the interview rather than the course activities would have been increased. This potential bias was combated somewhat by adding participants as the process continued. These additional participants did not have earlier interview "tutoring" sessions.

The interviewer is the instrument of data collection. This approach has both advantages and disadvantages with regards to bias in the data. First, because the interviewer had experience with the subject, she could direct the interview towards the objectives and remain on the focus topic. However, she may also have had anticipated responses based upon her own experience. This possible bias was addressed by eliciting open-ended responses to the interview questions. Thus, the participant was able to choose the answer and its direction.

3.5 *Summary of Research Design*

This investigation uses a phenomenological approach as defined by Creswell (1998). It employs a series of semi-structured focused interviews. A protocol was created for each interview. These protocols covered a number of content contextual areas that were part of a two-semester calculus-based introductory physics course. The conceptual questions in the protocols varied contextual features in the presented scenarios to determine students' mental models regarding Newton's Second Law.

The student participants were chosen via a "convenience" sampling method. After further scrutiny, the sample was also deemed meet "maximum variation" sampling criterion as well.

Each student participant was informed of the nature of the research project prior to the interviews and consent obtained.   Each interview was recorded onto audiotape and transcribed.

CHAPTER 4 – DATA ANALYSIS AND INTERPRETATION

Twenty-two students were interviewed during a two-semester calculus-based introductory physics course. A total of 71 interviews were conducted using a series of 6 different interview protocols. Not every student was interviewed each time. Each interview session was audio tape recorded resulting in about 42 hours of recorded data. This mass of data must be analyzed in some manner.

4.1 *Data Analysis Method*

A wide variety of student responses were collected during this in-depth phenomenological study. Merriam-Webster's Online Dictionary (2003) defines phenomenology as used here as "an analysis produced by phenomenological investigation" or alternatively "the typological classification of a class of phenomena". The alternative definition hints as to how to get to the first definition. This process of classification is generally termed qualitative data analysis. Patton (1983, p. 268) defines qualitative data analysis as "the process of bringing order to data, organizing what is there into patterns, categories and basic descriptive units".

McCraken (1988), Marshall and Rossman (1999), Bogdan and Bilken (1998), Seidman (1998), Creswell (1998; 2002) as well as Patton (1983; 1990) include classifying the data into categories as part of the task of understanding qualitative data. This small statement is much more than trivial. The rest of the task involves interpreting what these categories mean or signify with respect to the research questions asked. These tasks are addressed in Section 4.4 and Chapter 5 respectively.

4.2 *Data Manipulation and Reduction*

The researcher transcribed all the interviews with some small help from an assistant on two interviews that were verified by the researcher afterward. The transcriptions were not verbatim. Only student responses that were relevant to the protocol questions were transcribed carefully. Having no experience in transcription, the researcher devised methods of dealing with pauses, grunts, gestures, giggles and undecipherable phrases (sometimes uttered by the researcher herself!). As part of their answers, students may have also written or drawn on paper. These papers were also consulted during transcription and analysis.

These transcribed interviews were then reviewed along with the written responses. The student final responses were collected by question into an electronic spreadsheet. One may ask why final responses? Several students waffled on answers, adopting ideas and then rejecting them and/or changing answers to previous questions after a subsequent question had been asked and/or answered. These final responses were the ones settled on, sometimes checked for consistency and appeared to be believed most fully by the students. Portions of interview transcriptions displaying the waffling behavior are included in Appendix C.

As with many investigations, much data were collected, but only a small portion was relevant. Nine question scenarios provided information regarding student's use and understanding of Newton's Second Law. These questions and scenarios are listed in Table 4.2. Some of the questions are for comparison purposes and are included here for completeness. The detailed protocol for each interview is listed in Appendix A. The last column in the table is an abbreviation that will be used throughout the rest of the chapter. Only the responses to questions listed in Table 4.2 were placed into categories.

Table 4.2 Questions pertinent to Student's use and understanding of Newton's Second Law: Listed by Interview number.

	Contextual Scenario	Question	
2	Modified Atwood Machine with identical blocks: One on table and one hanging	If this is released from rest, what happens? Describe the motion	MA1
	Modified Atwood Machine with identical blocks: One on table and two hanging	If this is released from rest, what happens? Compare to above case.	MA2
3	Person on Sled Throwing off a Block every 10 seconds	What happens? Describe the motion of the sled.	SLD1
		(If velocity increases) Does that mean there is a force on the sled?	SLD2
4	Applying a Constant Force to Turn a Wrench	What is happens? Describe the motion.	WR1
	Block on a Spring in Simple Harmonic Motion	Does the Force Vary?	SHM1
		(If so) Does the Acceleration Vary?	SHM2
5	Equal charges: one fixed and one released from rest	What happens? Describe the motion	CH1
	Unequal charges: one fixed and one with larger mass released from rest	What happens? Compare to above case.	CH2
	Equal charges: one fixed and one traveling at velocity v	What happens? Describe the motion	CHV1
	Unequal charges: one fixed and one with larger mass traveling at velocity v	What happens? Compare to above case.	CHV2
	Charge placed in E-field zone and released from rest	What happens? Describe the motion	EF1
	Charge with larger mass placed in E-field zone and released from rest	What happens? Compare to above case.	EF2
	Charge traveling with velocity v towards E-field zone	What happens? Describe the motion	EFV1
	Charge with larger mass traveling with velocity v towards E-field zone	What happens? Compare to above case.	EFV2
6	Charge traveling with velocity v towards B-field zone	What happens? Describe the motion	BFV1
	Charge with larger mass traveling with velocity v towards B-field zone	What happens? Compare to above case.	BFV1

4.3 *Data Categorization*

The student responses were categorized in a two-level approach. First, the responses were listed as either completely consistent with Newton's Second Law or not. Secondly, those responses that were deemed not completely consistent with Newton's Second Law were categorized to represent the student's mental models where possible.

4.3.1 *First Level Categorization*

Rather strict categorization criteria were used in determining if a student response was consistent with Newton's Second Law. If clear connections between mass, acceleration and force were not made, then the response was classified as not completely consistent with Newton's Second Law.

Several student responses were not demonstrating explicitly correct uses of Newton's Second Law reasoning, but were along the correct path. As an example, compare the statement, "I would say slower than that one because it's bigger." (Student 14) to "So it has twice the mass, it will have half the acceleration because it will have the same force because it has the same charge" (Student 17). The latter statement is a clear and complete application of Newton's Second Law. Both responses were supported by drawn trajectories of particle paths. The response given by Student 14 does not show clearly if he sees the same force with a larger mass therefore the acceleration must be less so the motion is affected in likewise manner. However, the student could be, and likely is, thinking in this manner. These types of responses were categorized as Not Inconsistent with Newton's Second Law.

In addition, the interviews from the first semester, Interviews 1-4, did not always include changing the mass in the question protocols. Student responses to questions in these scenarios were only by chance able to be categorized in a similar manner as the response given by Student 17 above. Thus, nearly none fell into the Completely-Consistent-with-Newton's-Second-Law first level category. Some of the responses that were deemed consistent with Newton's Second Law were fully written out problem solutions. An example of a written response classified in this manner is presented in Figure 4.3.1.

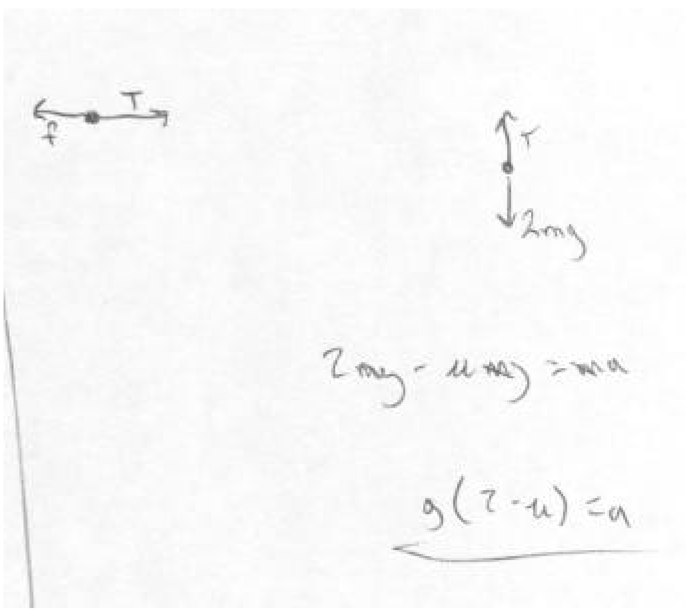


Figure 4.3.1 Written Response to Question MA2 (Student 1)

A student response was also classified in this manner if the student mentioned Newton's Second Law in their response: "If you want to find the acceleration then ma would equal –kx because of the two forces, so therefore a would be –kx over m…and if you're changing x, the spring constant and the mass are the same then the acceleration will vary." (Student 12)

These question scenarios changed the applied force and requested the student to compare situations. When a student correctly associated the applied force with the acceleration, the response was classified in the Not Inconsistent with Newton's Second Law Category. The results of the first level of classification are listed in Table 4.3.1.

Table 4.3.1 First Level Categorization of Student Reponses

Student	MA2	SLD2	WR1	SHM2	CH2	CHV2	EF2	EFV2	BFV1
1	NII	nii	nii	nii	O	O	O	O	NII
2	NII	O	nii	nii	NII	NII	nii	NII	NII
3	nii	nii	nii	nii					
4	nii	O	nii	nii					
5	nii			O					
6	NII	nii	NII	nii					
7	nii	O	O	nii	O	nii	O	O	O
8		nii	O	O					
9		nii	nii	nii	nii	NII	nii	NII	O
10		O	nii	nii					
11		O	O	O					
12		O	O	NII	O	O	O	O	O
13		nii							
14		nii	O		O	NII	NII	nii	O
15		O	nii		nii	nii	O	O	NII
16					O	O	O	O	O
17					NII	nii	NII	NII	NII
18					nii	nii	nii	nii	nii
19					nii	O	nii	O	O
20					nii	nii	NII	NII	NII
21					nii	NII	nii	nii	NII
22									

Legend:

NII	Completely consistent with Newton's Second Law
nii	Not Inconsistent with Newton's Second Law
O	Inconsistent with Newton's Second Law
	Student was not asked this question

4.3.2 *Second Level Categorization*

The responses deemed inconsistent with Newton's Second Law were then scrutinized further. Any response that was duplicated by more than one student was noted and a category created. Some responses were unique and therefore were not placed into any category besides inconsistent with Newton’s Second Law reasoning. The results of the second level of classification are listed in Table 4.3.2.

Table 4.3.2 Second Level Categorization of Student Reponses

Student	MA2	SLD2	WR1	SHM2	CH2	CHV2	EF2	EFV2	BFV1
1	NII	nii	nii	nii	M,E	M,E	M,E	M,E	NII
2	NII		nii	nii	NII	NII	nii	NII	NII
3	nii	nii	nii	nii					
4	nii		nii	nii					
5	nii								
6	NII	nii	NII	nii					
7	nii		A	nii	M,E	nii	Sz	Sz,Imp	M,E
8		nii	A						
9		nii	nii	nii	nii	NII	nii	NII	M,E
10			nii	nii					
11			A						
12			A	NII			Sz	Sz,Imp	Sz
13		nii							
14		nii	A		M,G	NII	NII	nii	A
15			nii		nii	nii	M	M,G	NII
16					M	M,A	M	M,A	M,E
17					NII	nii	NII	NII	NII
18					nii	nii	nii	nii,Imp	nii
19					nii	M	nii	M	M
20					nii	nii	NII	NII	NII
21					nii	NII	nii	nii	NII
22									

Legend:

A	Aristotelian
Imp	Impetus
M	Mass does not matter
E	Mass not in equations
G	Gauss’s Law
Sz	Size Matters
(grey)	Congruent with Newton’s Second Law
(black)	Student was not asked this question

4.3.3 *Second Level Categories*

As is apparent from inspection of Table 4.3.2 and its legend, a number of secondary categories exist. These categories were based upon both the transcribed student responses and their written responses, when available. Some student responses fell into more than one category. The classification criteria for each of these categories and its coded name are explained in the next sections.

4.3.3.1 *Aristotelian Category - A*

As stated in more detail in Chapter 2, Aristotle preceded Newton in theorizing about the motion of objects due to an applied force. His famous work stated that motion implies force: If no force is acting, the object is at rest. Also, that the velocity of a body is proportional to the force acting on it. These statements are very simplified version of a thorough and complex set of works that were accepted for hundreds of years (Ebison, 1993).

Some student responses clearly had Aristotelian reasoning patterns as their basis. These responses, such as “If it’s a constant force, I’m assuming a constant speed.” (Student 11) and “If the force is greater, then the velocity would have to be greater.” (Student 12) are associating force with velocity. These types of responses were classified as belonging to the Aristotelian second level category.

In addition to the transcriptions, the written responses were also reviewed. One student drew a force vector along the direction of particle initial velocity. See figures 4.3.3.1.a and 4.3.3.1.b.

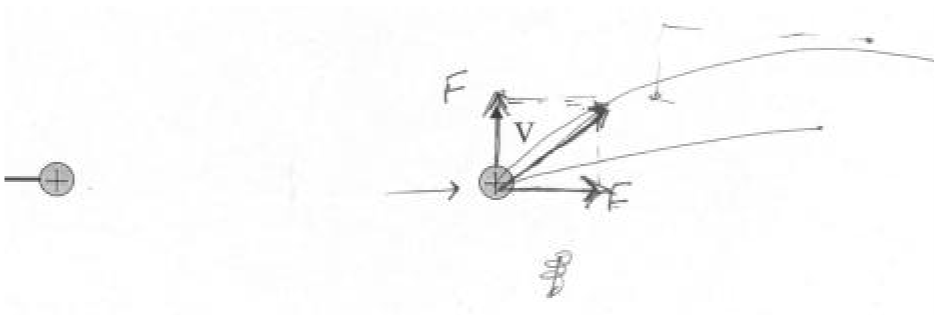


Figure 4.3.3.1.a Written Response to Question CHV1 (Student 16)

The transcript for this student's response reads: "If it's got a force pushing that direction [draws arrow along left-right axis] a force moving in that direction [labels the left-right arrow with F] and then I guess there's a force also moving in this direction [draws an arrow along velocity vector and labels it F] we've a velocity in that direction. So I would say that it would draw this vector here [draws diagonal arrow]. The force here [to the right away from fixed charge] and the force here [along v] will give it a net force here [along diagonal]" (Student 16).

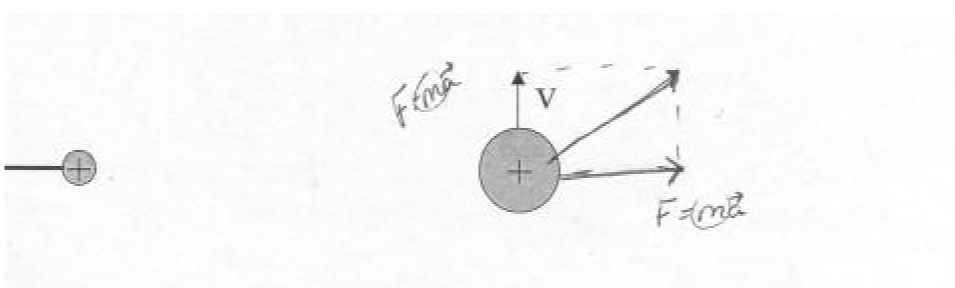


Figure 4.3.3.1.b Written Response to Question CHV2 (Student 16)

The transcript for this student's response reads: "I still don't I don't think the mass is going to matter because the mass is just some scalar value and the only thing that's changing is its acceleration and that's the only thing that's going to affect it" (Student 16).

Student 16 clearly associates a force with the velocity as in an Aristotelian style of reasoning. Interestingly, she also writes the Newton's Second Law equation and attempts to use it here. She clearly does not understand its application in this question scenario. Student 16 responses and others like them were categorized as Aristotelian.

4.3.3.2 *Impetus Category - Imp*

As stated previously in Chapter 2, the impetus theory of object motion dates to the 14^{th} century. It defines the 'imprinting from a body onto a moved (projectile)' as impetus, 'a permanent quality which is acquired and possessed by any moving body' (Giannetto 1993, p. 232-233).

The student responses that were classified as the Impetus category gave the object some sort of memory such that it returned to its initial velocity complete with direction after interacting with a force. This memory of the initial state was most apparent in the written responses. See Figure 4.3.3.2.

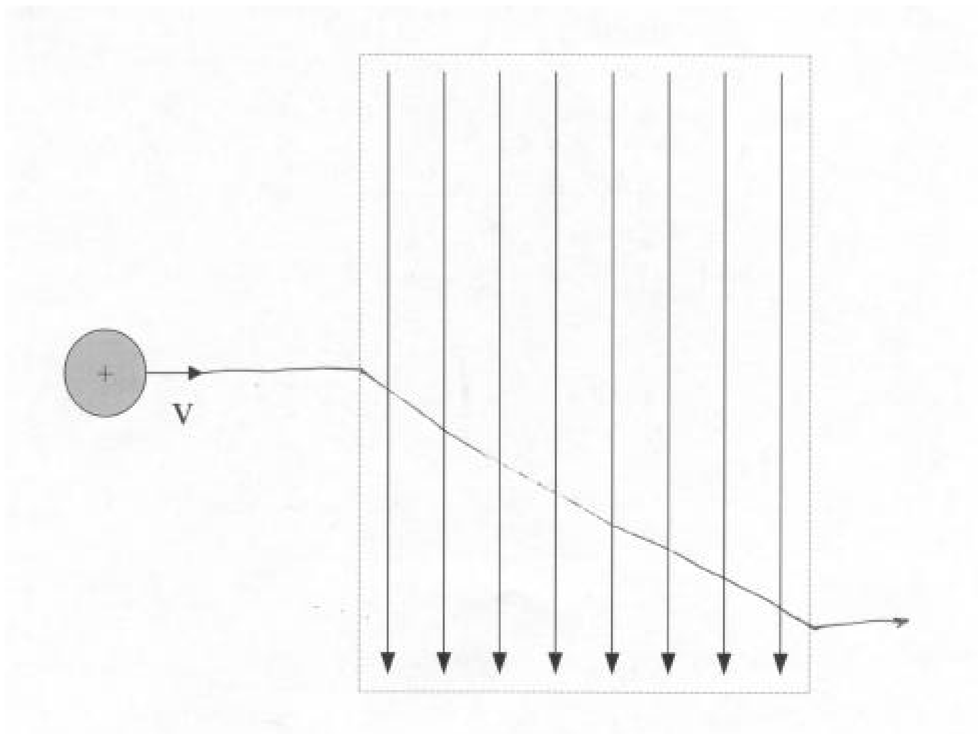


Figure 4.3.3.2 Written Response to Question EFV2 (Student 7)

The transcript for the student whose drawing appears in Figure 4.3.3.2 reads: "I would say it moves straight on as well and then it will go at more of an angle and then go straight as well. And then it will move at more of an angle because it since it's bigger will also would encounter more of the electric field as it passes." (Student 7)

Student 7 sees the particle retaining something from its original state and returning to it. This 'memory' placed this student response and another similar to it into the Impetus second level category.

4.3.3.3 *Mass Does Not Matter Category – M*

This category included student responses that imply or state that mass does not matter with respect to an object's motion. Usually this statement was explicit: "The mass I mean is not gonna matter because it's still going the same velocity so I would say it's going to do the same thing." (Student 19) It was also reflected in comparing sets of the written responses. See Figures 4.3.3.3.a and 4.3.3.3.b

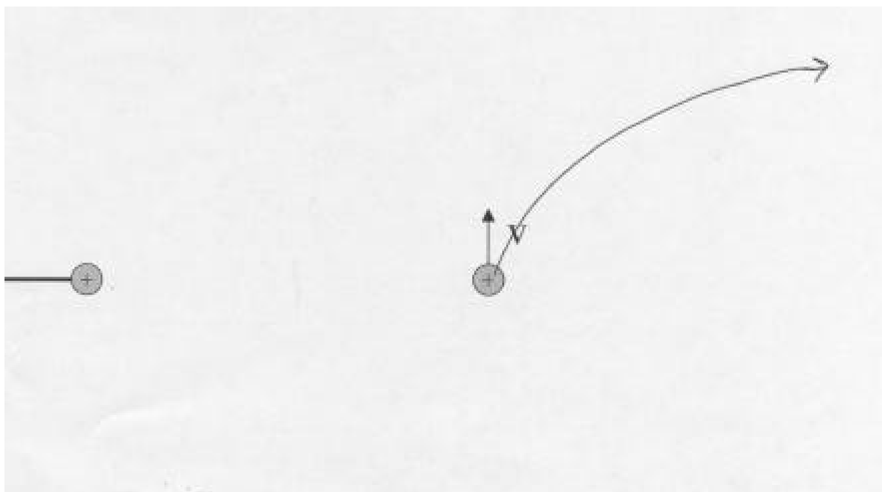


Figure 4.3.3.3.a Written Response to Question CHV1 (Student 1)

The transcript for the student whose drawing appears in Figure 4.3.3.3.a reads: "I figured it would just go…[Draws an arc away from fixed charge] something like that. This one is moving this way - this is still going to give it some component there [away] but it has this one initially so just combine the two." (Student 1)

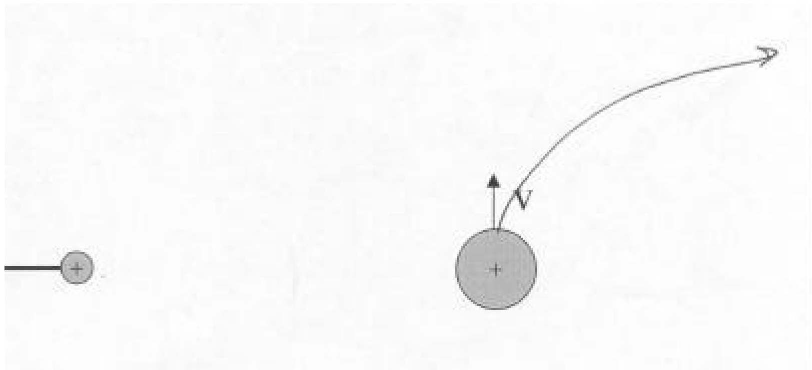


Figure 4.3.3.3.b Written Response to Question CHV2 (Student 1)

The transcript for the student whose drawing appears in Figure 4.3.3.3.b reads: "This one will do the same exact one as #1. [Interviewer: Why?] Well, like just in any equation we use the size the mass hasn't really come to play." (Student 1)

Student 1 explicitly showed that mass did not matter by drawing the trajectory of the particles identically even though the masses were different. In addition, reasons were given for that statement. Those reasons were also categorized leading to multiple categories for student responses.

4.3.3.4 *Equation Category - E*

The statement by Student 1 "like just in any equation we use the size the mass hasn't really come to play" was reiterated by a number of students as their reason for mass not affecting the motion in the charge and field question scenarios. Another student stated: "Since it's q v cross B [writing] so this will…there is no m over here so it doesn't matter on the mass." (Student 9) This theme was common. The popular equations to reference were for Coulomb forces, electric fields or magnetic forces. All student responses referring to mass as absent from an equation were classified into this category.

4.3.3.5 *Gauss's Law Category - G*

Another reason students cited for mass not affecting the motion was Gauss's law. The responses included statements like "If it has the same charge, I think you can assume it's a point charge…and assume that since the charge encl…make it a Gaussian surface whatever, the charge enclosed is identical." (Student 15) Only 2 student responses were classified as belonging in the Gauss's Law Category.

4.3.3.6 *Size Category - Sz*

In the field question scenarios, the increase in physical size as opposed to the mass was cited by two students as the mechanism for changing the motion. This increase in size provided a greater interaction with the field and thus a greater force. "Here the radius is 2 times the radius from before so that one has a bigger area that can be affected so then more field lines can affect the particle, the charged particle so it should, it should move probably faster than the original." (Student 12) This statement demonstrates a misunderstanding of field theory. However, if the student tacitly included mass into the reasoning as well as the size, the effects of Newton's Second Law and the increased force from the greater field interaction would counter each other. Thus, different discussions and drawings would have occurred. These student responses were classified as belonging to the Size category.

4.3.4 *Verification of Categorization*

Since the researcher was directly involved with both the data collection and manipulation, verification of the categorization was prudent. A second researcher not involved in the study in any way was given the Interview 6 transcripts of 4 disparate students. This independent researcher performed a primary level categorization of the student responses to the relevant questions. The results were identical to the classification by the study researcher.

In addition, the independent researcher also checked a random sample of student responses from the other question scenarios. Differences in first level categorization occurred with only 1 student response. .

Overall, 11 student responses were checked out of 115 responses used in the data analysis. Of these, only one response was not in agreement. This constitutes a 91% agreement rate of the nearly 10% of responses checked.

4.3.5 *Other Observations*

In categorizing the student responses with respect to Newton's Second Law, a couple of other patterns emerged. These issues were not part of the focus of the study and therefore not followed up or investigated deeply. The researcher was surprised by them and noted them as items for further study.

4.3.5.1 *Field Theory Issues*

As shown above in the Size Category, some students had difficulty with field theory. This observation was reflected not only in the size category but also in some of the responses to the distracter questions.

In one set of distracter questions, an additional field was placed adjacent and parallel to the electric field zone. Basically, the field zone was increased in size but not in strength. The charged particle placement was the same as in the first case making it now in the left half of the larger field zone. See figure 4.3.5.1.a.

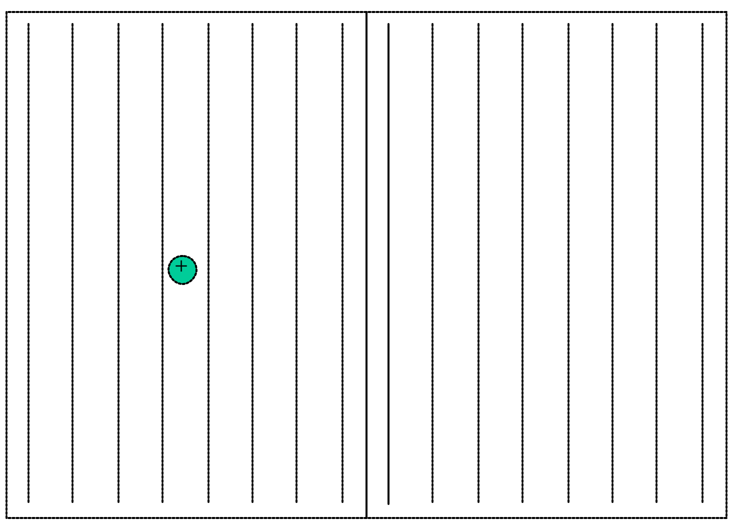


Figure 4.3.5.1.a Parallel Additional Electric Field Placement

Two students thought this placement would affect the trajectory of the particle:

> "It'll push it this way [away from additional field] a little bit. 'Cause like these, it will still travel down but it'll [gestures a curve] – cause you don't have anything over here to cancel out the components over there." (Student 1)

"Because the field strength is double, I guess the force is doubled so it's going to be accelerated in the opposite direction with twice the acceleration until it reaches the edge of the box and then it's just constant velocity." (Student 21)

An additional student joined those two when the field was added adjacent and anti-parallel to the electric field zone as in Figure 4.3.5.1.b: "It will kinda move to the middle and stay there." (Student 12)

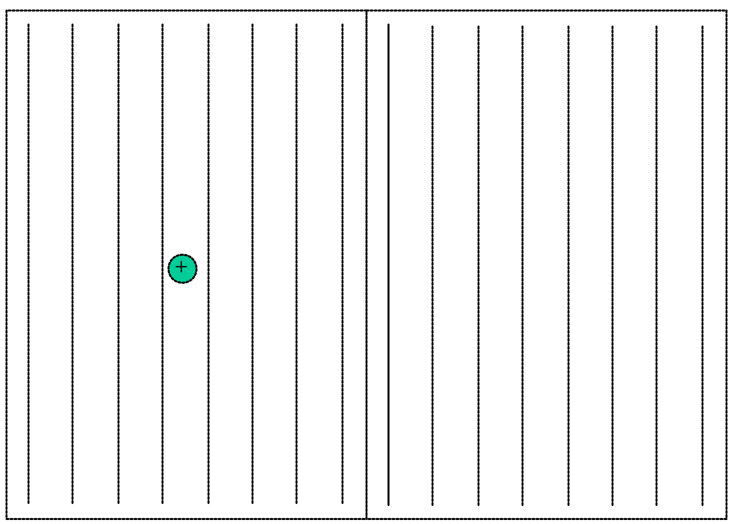


Figure 4.3.5.1.b Anti-Parallel Additional Electric Field Placement

In response to the Electric Field scenario questions, a few students drew charges at either end of the electric field zone. See Figure 4.3.5.1.c for an example. They apparently needed some tie to the field source. This assertion is further strengthened by the fact that one student asked the interviewer how the field could be made. Another student even had the notion that the field itself could be charged or uncharged: "Well um, do we know the charge on the electric field? Is it positive or negative?" (Student 18)

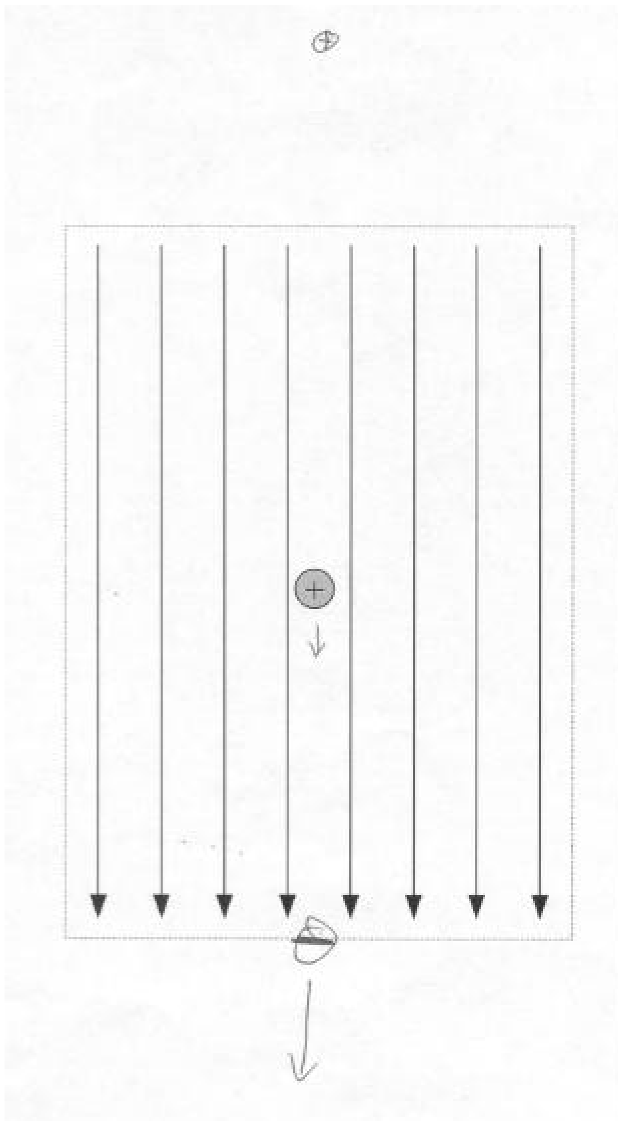


Figure 4.3.5.1.c Written Response to Question EFV1 (Student 15)

4.3.5.2 *Diminishing Forces*

Another trend was noted in reviewing student responses to the charge scenario questions CH1 and CHV1. The CH1 scenario involves equal charges, one fixed and one released from rest. All the students reported that the free charge would be repelled by the fixed charge. A majority of student responses included the fact that since the force diminishes as $1/r^2$ the particle would slow as it moves away from the other charge. A point was referenced where the particle's speed would reach a maximum and then start to return to either some constant velocity or zero.

> "It would accelerate at the beginning until it reached a certain point I suppose where the field isn't so strong on it." (Student 7)

> "So it'll at first it will probably accelerate and then get to a point when it starts slowing down again..." (Student 18)

This idea was presented by several students. Some of whom responded to the next question in the interview in a Newtonian manner and some who did not. This idea of slowing down was so prevalent that it could be eliminated as a possibility in only one student response.

This logic was also referenced in student responses to the CHV1 question and was also reflected in their written responses. See Figure 4.3.5.2. This question scenario also includes two identical charges, but the free one is moving at a velocity perpendicular to the force created by the fixed charge.

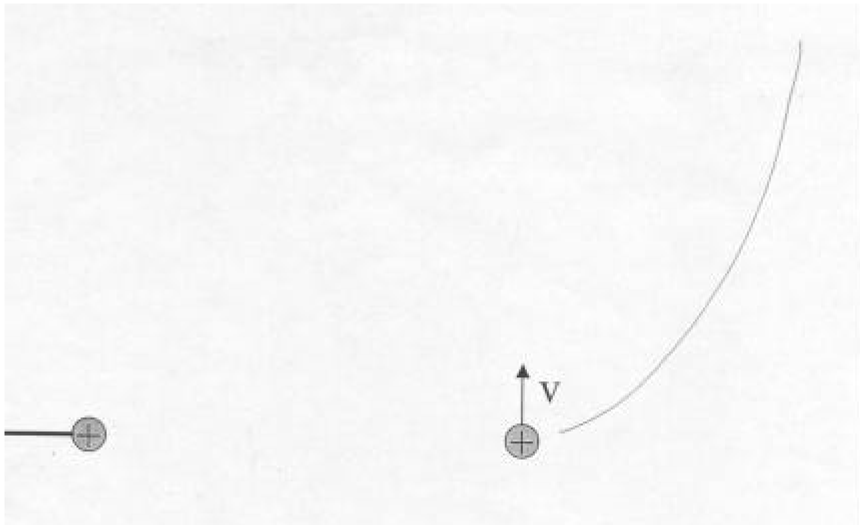


Figure 4.3.5.2 Written Response to Question CHV1 (Student 17)

The transcript for the student whose drawing appears in Figure 4.3.5.2 reads: "I would say that it should be accelerated in that direction but it will slow down as it gets farther away. So it should move [draws concave arc]" (Student 17)

4.4 *Data Interpretation*

Bogdan and Bilken (1998) conclude qualitative data analysis with the organization and coding of all the data that was collected. In their view, the only remaining task is to draw conclusions. However, many other authors and researchers do not agree. Seidman (1998) describes the next step as making themes. He defines a theme as "connections between the various categories" (Seidman, 1998), p. 107). McCracken (1988, p. 42) states "the object of analysis is the determination of patterns of intertheme consistency and contradiction." Marshall and Rossman (1999) refer to these themes as

Emergent Understandings where Patton (1980) and Creswell (1998) both refer to this process as Interpretation.

Table 4.3.2 was modified to simplify this process. The responses were grouped into two categories: Congruent with Newton's Second Law and Incongruent with Newton's Second Law. Students 13 and 22 were eliminated because they responded to only one question or fewer so comparisons between responses could not be made. Responses categorized as NII or nii were deemed as congruent with Newton's Second Law and all other left as non-Newtonian. Total numbers of Newtonian responses and percentages were calculated. The results are shown in Table 4.4.

Table 4.4 Simplified Categorization of Student Reponses

	First Semester Questions				Second Semester Questions							
St#	MA2	SLD2	WR1	SHM2	CH2	CHV2	EF2	EFV2	BFV1	# NII	# Q	% NII
1										5	9	56
2										8	9	89
3										4	4	100
4										3	4	75
5										1	2	50
6										4	4	100
7										3	9	33
8										1	3	33
9										7	8	88
10										2	3	67
11										0	3	0
12										1	8	13
14										4	7	57
15										4	8	50
16										0	5	0
17										5	5	100
18										5	5	100
19										2	5	40
20										5	5	100
21										5	5	100
#NII	7	6	8	9	8	9	8	7	7			
# Int	7	14	14	14	13	13	13	13	13			
% NII	100	43	57	64	62	69	62	54	54			

Legend:

- Congruent with Newton's Second Law
- Incongruent with Newton's Second Law
- Student Not Asked Question

4.4.1 *Overall Trends*

Of the three students who were asked all nine question scenarios, none gave Newtonian responses to every question. In viewing student responses per semester, four students gave consistently Newtonian responses in the first semester and a different five students did so in the second semester interviews. Comparisons between these sets of students are questionable because some of the students in the second semester were not interviewed during the first semester and vice versa. Still, between 30 and 38 percent was a rather small rate of use of Newton's Second Law reasoning.

The modified Atwood machine scenario question, MA2, had the highest percentage of Newtonian student responses. This result is not surprising since the students had been asked this very question in the course and the interview occurred in the time period when Newton's laws were part of course instruction.

The second place scenario, spring with an attached block - SHM, with 64% Newtonian response was also in the first semester. The Simple Harmonic Motion of a spring and a block was emphasized in the course. This particular instructor chose to spend more time on simple harmonic motion and forego gravitation.

4.4.2 *Contextual Dependence of Newton's Second Law*

The results of data categorization presented in Tables 4.3.2 and Table 4.4 were reviewed both from a contextual domain perspective and a student longitudinal perspective. From these perspectives some themes emerged.

4.4.2.1 *Sled Scenario Question*

The Sled scenario question, SLD2, had the least percentage of Newtonian responses. Six of the 14 students gave non-Newtonian responses. Students 2, 4 and 10 had this scenario as their only non-Newtonian response. This scenario used concepts which were employed in only one assigned homework question. And the homework question was labeled as an exercise versus a problem in the textbook (Halliday et al., 2001). This exercise label means that students merely had to determine the correct formula and the values required to correctly answer the question. Thus, this scenario was fairly unfamiliar to the students. Fewer students providing Newtonian reasoning was not surprising.

In addition, the phrasing of question SLD2 was less than optimal. Since the scenario dealt with both a sled and blocks being thrown from it, question SLD2 which asked about the sled alone caused some confusion. Also, the current topic of instruction was center of mass which was mentioned by several students.

4.4.2.2 *Wrench Scenario Question*

From the first semester questions, the only question scenario that elicited clear non-Newtonian reasoning was the wrench scenario question, WR1. To clarify this point Table 4.4.2.2 shows an excerpt from Table 4.3.2 with non-participating student responses omitted.

Table 4.4.2.2 First Semester Question Student Response Classification

	First Semester Questions			
Student	**MA2**	**SLD2**	**WR1**	**SHM2**
1	NII	nii	nii	nii
2	NII		nii	nii
3	nii	nii	nii	nii
4	nii		nii	nii
5	nii			
6	NII	nii	NII	nii
7	nii		A	nii
8		nii	A	
9		nii	nii	nii
10			nii	nii
11			A	
12			A	NII
14		nii	A	
15			nii	

Legend:

(light grey)	Congruent with Newton's Second Law
A	Aristotelian
(dark)	Student was not asked this question

The student responses were either Newtonian or Aristotelian in nature. The students understood the question scenario and seemed familiar with it. The students clearly used non-Newtonian reasoning in this question scenario.

Questions WR1 and SHM2 were asked during the same interview session. Students 7 and 12 gave Newtonian responses to SHM2 minutes after giving non-Newtonian responses to WR1.

4.4.2.3 *Electric Charge Scenario Questions*

In these scenarios, two charges are present: one is fixed, and one is free to move. In the CH questions, the free charge is released from rest. In the CHV questions the free charge is moving with a velocity perpendicular to the direction of the force created by the fixed charge. In both of these scenarios, the mass of the free charge is greater in question two than in question one. Again, an excerpt from Table 4.3.2 is included as Table 4.4.2.3 for ease of comparison.

Table 4.4.2.3 Electric Charge Question Scenario Student Response Classification

Student	CH2	CHV2
1	M,E	M,E
2	NII	NII
7	M,E	nii
9	nii	NII
12		
14	M,G	NII
15	nii	nii
16	M	M,A
17	NII	nii
18	nii	nii
19	nii	M
20	nii	nii
21	nii	NII

Legend:

(shaded)	Congruent with Newton's Second Law
A	Aristotelian
M	Mass does not matter
E	Mass not in equations
G	Gauss's Law

Many students gave Newtonian answers for this question scenario. Interestingly, in the responses that were non-Newtonian, all but one student provided 'mass does not matter' as a reason with some responses clarified further. The one student that did not agree with 'mass does not matter' had a very unique response that described the free charge in a sort of equilibrium. This response did not fall into any category.

Students 7, 14 and 19 had different reasoning for the charge starting from rest and the one starting with an initial velocity. The addition of velocity in this question scenario triggered two of these students to invoke reasoning congruent with Newton's Second Law. Conversely, student 19 did just the opposite. The addition of an initial velocity triggered that student to abandon the Newtonian reasoning used when the charge had started from rest.

4.4.2.4 *Electric Field Scenario Questions*

These question scenarios involved a zone of uniform electric field. In the EF questions, a charged particle is released from rest in the center of the electric field. In the EFV questions, the charged particle is traveling with a velocity toward and perpendicular to the electric field. Once again, the mass of the charged particle is greater in question two than question one.

Table 4.4.2.4 Electric Field Scenario Student Response Classification

Student	EF2	EFV2
1	M,E	M,E
2	nii	NII
7	Sz	Sz,Imp
9	nii	NII
12	Sz	Sz,Imp
14	NII	nii
15	M	M,G
16	M	M,A
17	NII	NII
18	nii	nii,Imp
19	nii	M
20	NII	NII
21	nii	nii

Legend:

(shaded)	Congruent with Newton's Second Law
A	Aristotelian
Imp	Impetus
M	Mass does not matter
E	Mass not in Equations
G	Gauss's Law
Sz	Size Matters

Again focusing on the non-Newtonian responses, all students indicated or implied that mass does not matter. Recall in section 4.3.3.6 that the Size category grouped the responses that stated the size of the charged particle caused a greater force from the field with no mention of the mass increase countering that effect. In addition, a field is required for the reasoning pattern classified as the Size category to be employed. So EF and EFV scenarios were the first to have Size as a category of student responses.

Also, EFV was the only question scenario where responses were classified as belonging to the Impetus category. This Impetus classification was in conjunction with the categorization of the responses as either Newtonian or non-Newtonian.

4.4.2.5 *Magnetic Field Scenario Question*

The BFV question scenario was nearly identical to the EFV scenario. The notable difference being that the student chose which direction the B-Field zone should point with respect to the initial velocity of the charged particle in order to draw the trajectory of the particle's motion. The excerpted portions of Table 4.3.2 are listed below in Table 4.4.2.5

Table 4.4.2.5 Magnetic Field Scenario Student Response Classification

Student	BFV1
1	NII
2	NII
7	M,E
9	M,E
12	Sz
14	A
15	NII
16	M,E
17	NII
18	nii
19	M
20	NII
21	NII

Legend:

(shaded)	Congruent with Newton's Second Law
A	Aristotelian
M	Mass does not matter
E	Mass not in Equations
Sz	Size Matters

Again, the non-Newtonian response that includes or implies mass does not matter was the most common. Student 14 indicated that mass mattered but used clear Aristotelian-based reasoning. This response was the only occurrence of this type of reasoning in the second semester questions.

4.4.3 *Longitudinal Themes*

Several themes emerged from a review of Table 4.4. To aid in this review Table 4.4 was reordered by percentage of Newtonian responses as Table 4.4.3.

Table 4.4.3 Simplified Categorization of Student Reponses: Sorted by %N

	First Semester Questions				Second Semester Questions							
St#	MA2	SLD2	WR1	SHM2	CH2	CHV2	EF2	EFV2	BFV1	# NII	# Q	% NII
3	▒	▒	▒	▒	■	■	■	■	■	4	4	100
6	▒	▒	▒	▒	■	■	■	■	■	4	4	100
17	■	■	■	■	▒	▒	▒	▒	▒	5	5	100
18	■	■	■	■	▒	▒	▒	▒	▒	5	5	100
20	■	■	■	■	▒	▒	▒	▒	▒	5	5	100
21	■	■	■	■	▒	▒	▒	▒	▒	5	5	100
2	▒	□	▒	▒	▒	▒	▒	▒	▒	8	9	89
9	■	▒	▒	▒	▒	▒	▒	▒	□	7	8	88
4	▒	□	▒	▒	■	■	■	■	■	3	4	75
10	■	□	▒	▒	■	■	■	■	■	2	3	67
14	■	▒	□	■	□	▒	▒	▒	□	4	7	57
1	▒	▒	▒	▒	□	□	□	□	▒	5	9	56
5	▒	■	■	□	■	■	■	■	■	1	2	50
15	■	□	▒	□	▒	▒	□	□	▒	4	8	50
19	■	■	■	■	▒	□	▒	□	□	2	5	40
7	▒	□	□	▒	□	▒	□	□	□	3	9	33
8	■	▒	□	□	■	■	■	■	■	1	3	33
12	■	□	□	▒	□	□	□	□	□	1	8	13
11	■	□	□	□	■	■	■	■	■	0	3	0
16	■	■	■	■	□	□	□	□	□	0	5	0

Legend:

▒ Congruent with Newton's Second Law
□ Incongruent with Newton's Second Law
■ Student Not Asked Question

Students 2, 3, 6, 9, 17, 18, 20 and 21 fairly consistently gave Newtonian responses throughout the questions each was asked. Similarly, Students 11, 12 and 16 fairly consistently responded in a non-Newtonian manner.

Student 1 abandoned Newton's Second Law in his responses starting with the second semester questions. Student 9 abandoned Newton's Second Law later in response to the magnetic field question scenario, BFV.

Students 7, 14, 15 and 19 toggled in and out of Newtonian reasoning patterns as the questions were asked. Student 14 had an early Aristotelian response, changed to Newtonian responses and then returned to Aristotelian reasoning in the final interview.

As mentioned above in Section 4.4.2.4, the introduction of an initial velocity in the charge scenario CHV caused Students 7, 14 and 19 to change their reasoning. But only Student 19 changed reasoning when velocity was introduced in the electric field scenario EFV as well, and kept to that reasoning base in responding to question scenario BFV in the next interview session.

Students 7 and 12 employed the Size reasoning for electric field question scenarios. However, only Student 12 continued this reasoning into the magnetic field question scenario.

4.4.3.1 *Tenacity of Non-Newtonian Reasoning*

As was stated in Section 3.4.2, ethical considerations necessitated that the students be tutored after each interview session. This tutoring was one-on-one between the student and the researcher. The researcher employed Socratic dialog to help students discover discrepancies between his or her responses and Newtonian-based reasoning solutions. For students who did have Newtonian responses, the researcher confirmed the students' understanding during the tutoring portion of the interview session.

. Despite these individual tutoring sessions, non-Newtonian reasoning was still prevalent in subsequent interviews. Table 4.3.2 is reproduced below as Table 4.4.3.1 including indications when the tutoring occurred.

Table 4.4.3.1 Second Level Categorization of Student Reponses:
Dark lines indicate where tutoring occurred.

Student	MA2	SLD2	WR1	SHM2	CH2	CHV2	EF2	EFV2	BFV1
1	NII	nii	nii	nii	M,E	M,E	M,E	M,E	NII
2	NII		nii	nii	NII	NII	nii	NII	NII
3	nii	nii	nii	nii					
4	nii		nii	nii					
5	nii								
6	NII	nii	NII	nii					
7	nii		A	nii	M,E	nii	Sz	Sz,Imp	M,E
8		nii	A						
9		nii	nii	nii	nii	NII	nii	NII	M,E
10			nii	nii					
11			A						
12			A	NII			Sz	Sz,Imp	Sz
14		nii	A		M,G	NII	NII	nii	A
15			nii		nii	nii	M	M,G	NII
16					M	M,A	M	M,A	M,E
17					NII	nii	NII	NII	NII
18					nii	nii	nii	nii,Imp	nii
19					nii	M	nii	M	M
20					nii	nii	NII	NII	NII
21					nii	NII	nii	nii	NII

Legend:

A	Aristotelian
Imp	Impetus
M	Mass does not matter
Eq	Mass not in equations
G	Gauss's Law
Sz	Size Matters
	Congruent with Newton's Second Law

Tutoring

The tutoring that occurred between questions SLD2 and WR1 was not effective for Students 7, 8, 11, 12, and 14. Students 7, 11 and 12 used non-Newtonian responses to both questions. Students 8 and 14 both gave Newtonian responses for the first question but not the second.

The tutoring between questions EFV2 and BFV1 was effective for at least one student. "The last time I didn't, I just wanted to say mass doesn't matter but it does." (Student 1) Student 18 also appeared to benefit from tutoring. His written response to question BFV1 did not include a return to the initial velocity direction indicative of the Impetus category. Additionally, Student 7 moved from a Size category of response to a Mass Does Not Matter and Equation categories of response for these similar question scenarios. The tutoring did not change his reasoning to be consistent with Newtonian thinking, but it did change it to where Student 1 was prior to the tutoring.

This tutoring did not change the primary response category of several students. Particularly, Students 17, 2, 16, and 19 responses were consistent between question scenarios with tutoring sessions occurring between them. And Students 9 and 14 actually gave Newtonian responses to EFV2 and reverted to non-Newtonian reasoning in responding to question BFV1 after tutoring.

.

4.4.4 *Course Performance Comparisons*

Final semester course scores were obtained for comparison and percentages calculated. Tables 4.4.4.1 and 4.4.4.2 list these scores by semester. Most of the students had taken the first semester course in the spring of 2002. The student scores from other semesters result from different assessment measures given by a different instructor. Their scores were not included in the study since the comparison would not be valid. The students had quite a performance range. Understandably the performance range was narrower for the second semester students since they had to pass the first semester course beforehand.

4.4.4.1 *First Semester Performance*

Table 4.4.4.1 shows that Newtonian responses to these questions were not apparently correlated with the final score in the course. Figures 4.4.4.1.a and 4.4.4.1.b display it graphically.

Table 4.4.4.1 Student Final Course Scores for First Semester Questions

St #	MA2	SLD2	WR1	SHM2	# N	# Questions	% Newtonian	1st Sem Score
1	N	N	N	N	4	4	100	88.3
3	N	N	N	N	4	4	100	98.5
6	N	N	N	N	4	4	100	54.7
9		N	N	N	3	3	100	91.0
2	N		N	N	3	4	75	94.7
4	N		N	N	3	4	75	78.7
10			N	N	2	3	67	81.3
7	N			N	2	4	50	87.2
14		N			1	2	50	88.6
8		N			1	3	33	45.9
12				N	1	3	33	76.2
15			N		1	3	33	90.3
11					0	3	0	78.3
Class Average Score (154 Students)				77.2	Student Participant Average Score		62.0	81.0
Standard Deviation				13.7	Standard Deviation		31.5	15.2

Student 6 was completely Newtonian in all responses given but only attained a score of 55% in the course. Conversely, Student 15 responded congruent with Newtonian reasoning for only one question but still earned a 90% score in the course.

A Wilcoxon matched-pairs signed-rank test was performed on the data. This non-parametric statistical test compares the shape of the distribution for each set of data. The comparison is accomplished by ranking the differences between the matched sets of data and tracking where a data point changed rank. A T value of 19 was calculated which is well above the accepted significance level of 10. This statistically shows that the Newtonian response rate does not correlate to the course score which is reflected in the graphical representations in Figures 4.4.4.1.a and 4.4.4.2.b. This result was a bit surprising to the author since the first semester course primarily covered mechanics and kinematics where Newtonian reasoning is thought to be advantageous. However, it is similar to the findings of Cohen, Hillman and Agne (1978), p. 1028) "Final course grade, may not be the best measure of actual achievement in physics"

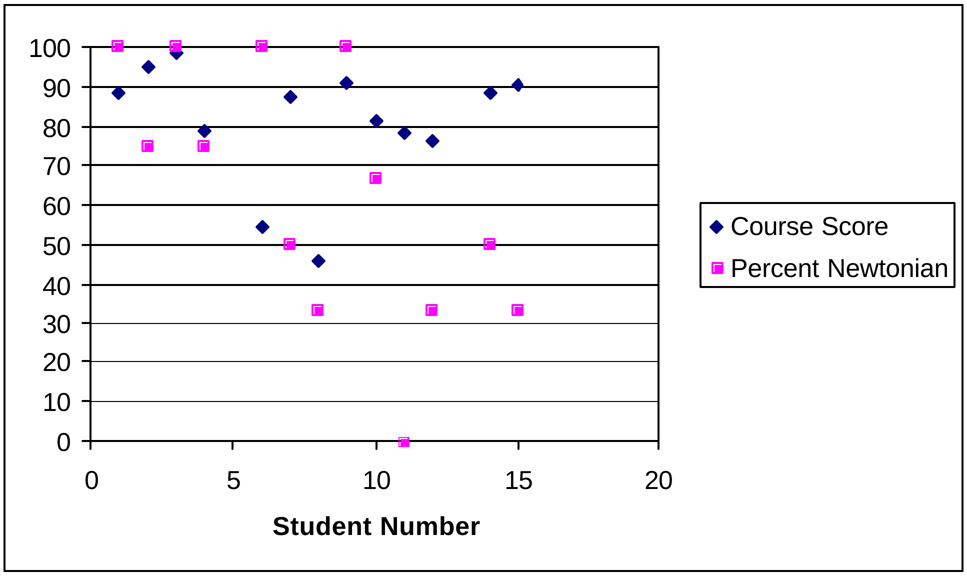


Figure 4.4.4.1.a First Semester Student Performance and Newtonian Responses

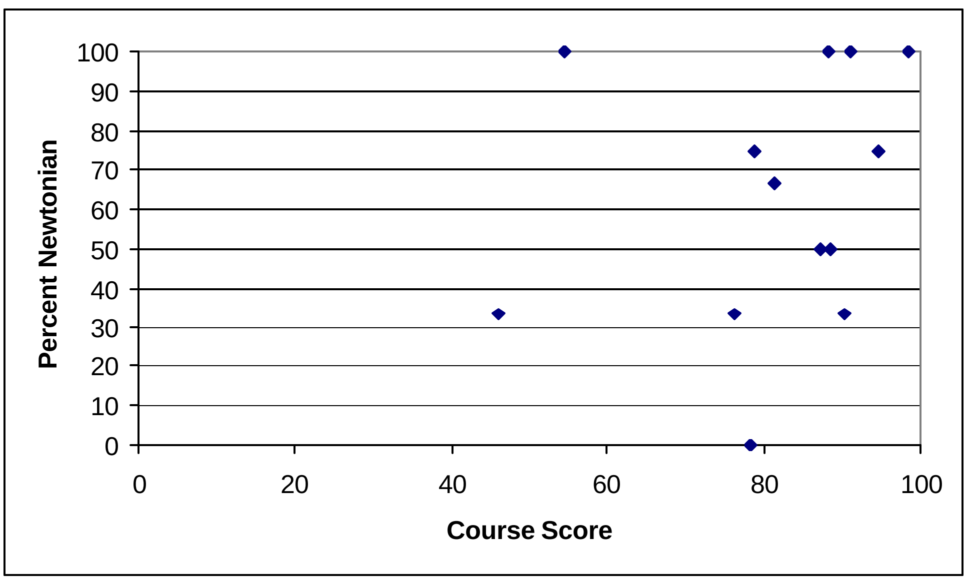


Figure 4.4.4.1.b First Semester Percentage of Newtonian Responses versus Course Score

4.4.4.2 *Second Semester Performance*

Again the scores were averaged and put into Table 4.4.4.2 and graphically displayed in Figures 4.4.4.2.a and 4.4.4.2.b. The second semester participant average score was only slightly better.

Table 4.4.4.2 Student Final Course Scores for Second Semester Questions

St #	CH2	CHV2	EF2	EFV2	BFV1	# N	# Quest	% N	2nd Sem Score (%)
2	N	N	N	N	N	5	5	100	93.6
17	N	N	N	N	N	5	5	100	92.7
18	N	N	N	N	N	5	5	100	66.8
20	N	N	N	N	N	5	5	100	83.5
21	N	N	N	N	N	5	5	100	94.8
9	N	N	N	N		4	5	80	85.2
14		N	N	N		3	5	60	87.8
15	N	N			N	3	5	60	88.4
19	N		N			2	5	40	67.7
1					N	1	5	20	84.8
7		N				1	5	20	77.9
12						0	5	0	70.8
16						0	5	0	85.4
Class Average Score (129 Students)					63.8	Student Participant Average		60.0	83.0
Standard Deviation					24.0	Standard Deviation		40.0	9.5

Student 18 consistently used Newtonian responses but still earned a 67%. A score of about 85% was attained by students with Newtonian response percentages of 100 (Student 20), 80 (Student 9), 60 (Student 15), 20 (Student 1) and 0 (Student 16).

Similarly, a Wilcoxon matched-pairs signed-rank test calculated a T value of 23 that is well above the accepted significance level of 10. This statistically shows that the Newtonian response rate does not correlate to the course score which agrees with the graphical representations in Figures 4.4.4.2.a and 4.4.4.2.b. Again course performance is not correlated with correct reasoning regarding Newton's Second Law.

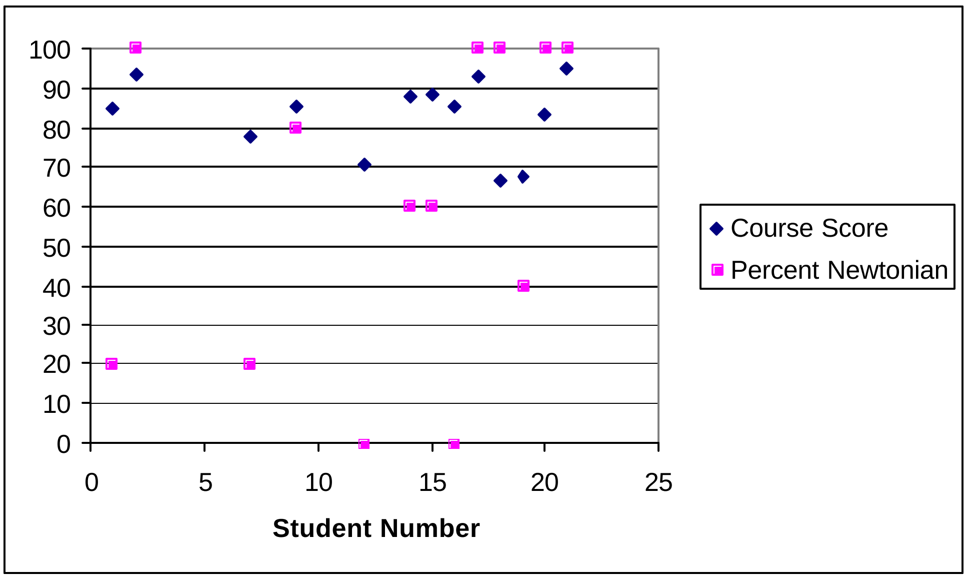


Figure 4.4.4.2.a Second Semester Student Performance and Newtonian Responses

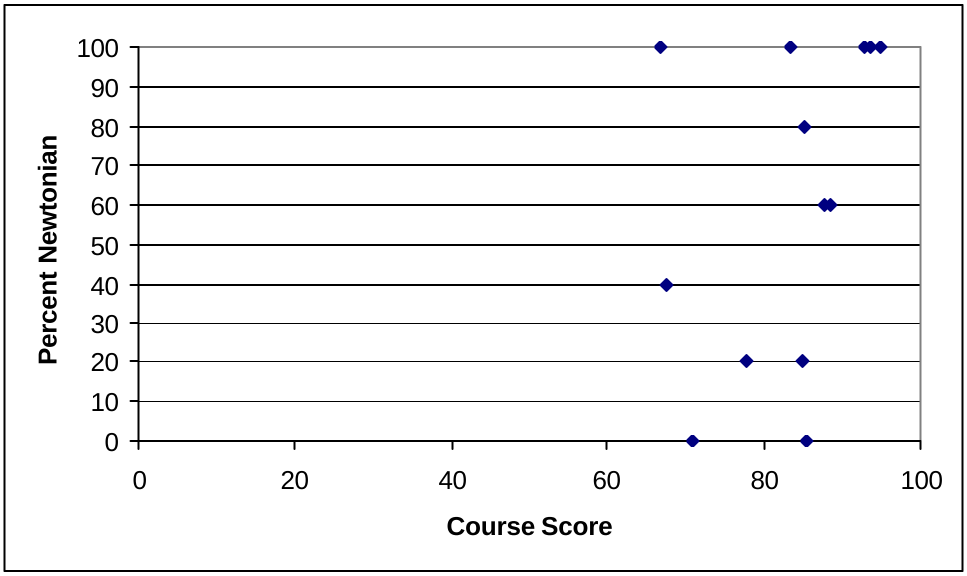


Figure 4.4.4.2.b Second Semester Percentage of Newtonian Responses versus Course Score

Caution must be taken when viewing these findings. The questions in these scenarios were conceptual. Little quantitative problem solving was required. Specifically in the field and charge scenarios, the questions were not anything like questions posed on exams, quizzes or homework in the course. The course assessments required rather traditional problem solving, particularly in the first semester. The second semester included conceptual questions in its assessment. However, field theory concepts and not Newtonian concepts were included.

4.4.4.3 *Do Physics Majors Perform Better?*

Anecdotally, physics faculty have made many statements that imply that physics majors perform better and conceptually understand more than engineering students. To see if this study refuted or supported that perspective, the course scores of the physics majors who participated are listed separately in Tables 4.4.4.3.a and 4.4.4.3.b. These students are all male. They were in the same class sections and thus, received identical instruction.

Table 4.4.4.3.a Physics Major Final Course Scores for First Semester Questions

St #	MA2	SLD2	WR1	SHM2	# N	# Questions	% Newtonian	1st Sem Score
1	N	N	N	N	4	4	100	88
2	N		N	N	3	4	75	95
7	N			N	2	4	50	87
14		N			1	2	50	89
Class Average Score (154 Students)				77.2	Student Participant Average Score		62	79.5
Standard Deviation				13.7	Standard Deviation		31.5	17.9

Table 4.4.4.3.b Physics Major Final Course Scores for Second Semester Questions

St #	CH2	CHV2	EF2	EFV2	BFV1	# N	# Quest	% N	2nd Sem Score (%)
2	N	N	N	N	N	5	5	100	94
14		N	N	N		3	5	60	88
1					N	1	5	20	85
7		N				1	5	20	78
Class Average Score (129 Students)					64	Student Participant Average		60	83
Standard Deviation					24.0	Standard Deviation		40.0	9.5

In both semesters, the physics majors scored better than average on course assessments. However, if the percentage of Newtonian responses were used as a metric of conceptual understanding, they do not fare as well. Half of the physics majors were below average in Newtonian responses to the first semester questions which were more mechanics based. Three-quarters of the physics majors were average or below with respect to percentage of Newtonian responses to the second semester questions.

These four students are hardly representative of physics majors across the country. And given the small number of participants they are not necessarily representative of physics majors at Kansas State University either. These data are considered anecdotal at best and can only be used as such.

4.4.4.3 *Summary*

The interview data were transcribed and organized. All of the data that were collected during the student interviews was reviewed, reduced and categorized in a two-level approach. Some observations from review and categorization of the data were noted for further study.

The categories were further scrutinized from both a scenario question perspective and longitudinal student perspective. Some themes of contextual dependence and student inconsistency emerged. Additionally, student interview results were compared with course performance to see if any correlation existed.

CHAPTER 5 – RESULTS AND CONCLUSIONS

The purpose of this study was to investigate student's use and understanding of Newton's Second Law in contextual scenarios different from those used during instruction by probing into student mental models and reasoning across a two-semester course. A series of interviews was conducted with student participants enrolled in a calculus-based introductory physics course. Assigned homework problems were selected as the basis for the interview protocols. The interview questions were conceptually based to reveal student understanding and underlying mental models.

Since this study did not involve hundreds of students, the data cannot be generalized to a larger population of physics students. And, from the Chi-Squared goodness-of-fit-test performed on the students' final course scores, the participants did not fully represent the population of students enrolled in the calculus-based introductory course at Kansas State University. However, the student participants were better performers on average than their peers. Thus, their responses of an 'incorrect' nature hold more value. From these responses, trends and themes emerged that do provide answers to the research questions.

5.1 *After instruction in the course, do students continue to use and understand Newton's Second Law throughout the rest of the course topics?*

Four students responded in ways that were not inconsistent with Newton's Second Law reasoning for all of the second semester questions. Eleven student responses were categorized as Newtonian for at least one of the second semester questions. Twelve of the thirteen students interviewed during the first semester responded to at least one question in a way not inconsistent with Newton's Second Law. Three of those students answered all the first semester questions in a manner congruent with Newton's Second Law.

Conversely, these results show that students also do not use Newton's Second Law reasoning in the full range of course topics. The mental models used by students and classified into the Aristotelian or Impetus category confirm misconceptions found by other researchers (Clement, 1982; McCloskey, 1983b; Rebello et al., 2003). However, misconceptions were discovered that have not been previously documented. Particularly, the Equation, Size, and Gauss's Law categories of mental models has no precedent. These newly discovered misconceptions were illuminated by a more thorough look into the students' understanding in content areas differing from mechanics.

From this information, the conclusion can be made that some students do continue to use and appropriately apply Newton's Second Law after instruction has moved to other topics. However, individual student responses are not always consistent. Thus, the students' abilities to apply Newton's Second Law are dependent on the context in which they are asked to apply the concept. How the question context affects the students' choice of mental models is addressed by the next research question.

5.2 *Does question context affect the student's application of Newton's Second Law?*

For clarity of discussion and reference, the contextual scenarios and their abbreviations are listed again in Table 5.2 below.

Table 5.2 Question Scenario Descriptions and Abbreviations

Interview	Contextual Scenario	Abbreviation
2	Modified Atwood Machine with identical blocks: One on table and one hanging	MA
3	Person on Sled Throwing off a Block	SLD
4	Applying a Constant Force to Turn a Wrench	WR
	Block on a Spring in Simple Harmonic Motion	SHM
5	Equal charges: one fixed and one released from rest	CH
	Equal charges: one fixed and one traveling at velocity v	CHV
	Charge placed in E-field zone and released from rest	EF
	Charge traveling with velocity v towards Electric field zone	EFV
6	Charge traveling with velocity v towards Magnetic field zone	BFV

Scenarios SLD, EFV, and BFV had the least percentage of responses from the participants categorized as Not Inconsistent with Newton's Second Law. Two students used non-Newtonian mental models for only the SLD scenario questions. But as mentioned in Section 4.4.2.1, this result may have had as much to do with poor question delivery as with student reasoning.

One student reverted from consistently using Newtonian-based mental models for only the BFV scenario questions out of eight questions asked of him. Every indicator implies that this should not have occurred. The EFV and BFV scenarios are rather similar in nature. This student answered the EFV questions using a Newtonian-based mental model but not the BFV questions. Tutoring occurred between the EFV and BFV interview sessions as well which should have re-enforced the Newtonian-based mental model employed consistently up to that point by this student. It did not. Clearly for this student, the BFV scenario caused some consternation.

All of the student responses for WR scenario questions were categorized as either Aristotelian or Newtonian in nature. This either-or situation was not repeated in any other scenario. Additionally, the wrench scenario questions were followed by the SHM scenario question in the same interview session. Tutoring occurred at the end of the interview and so could not have come into play. Three student responses to SHM scenario questions were categorized differently than the responses to the WR scenario questions asked only minutes previously. These contextual scenarios definitely affected the student's choice in using Newton's Second Law.

Similarly, the CHV questions followed the CH scenario questions in the same interview session. Three student responses changed category between these two scenarios when an initial velocity was incorporated. However, only one of these students remained consistent with this adjustment when the velocity was added between EF and EFV scenarios. So the addition of an initial velocity triggered some students to change mental models.

More generally, student changed mental models between contexts (as defined in Section 2.4.1). Three students responded differently to the charge context (CH and CHV scenarios) than to the field context (EF, EFV and BFV scenarios) with respect to

Newton's Second Law reasoning. This result is further clarified by the categorization of the non-Newtonian responses. The Size and Impetus categories only appeared in the field context.

The above evidence clearly shows that question context does cause students to use various mental models in responding to differing scenario questions. However, these effects appear to be at an individual level. Nearly all of the question contexts had both Newtonian and non-Newtonian student responses. What triggers one student to use a Non-Newtonian model may trigger another to use a Newtonian model and vice versa. A clear indication that a certain context will cause more or less use of Newtonian-based mental models did not emerge from the data.

The evidence does not indicate that once a student changes from being consistent with Newton's Second Law he or she will remain inconsistent for the remainder of the course. Instead, some students switched back-and-forth between Newtonian and non-Newtonian mental models in responding to different scenario questions. The data provide few clues to any part of the scenarios that might have caused these switches.

Strong evidence indicates that rather small changes in a scenario can trigger a rather large change in the mental model that students are using. This change is most apparent in the differences in mental models between the CH and CHV and the EF and EFV scenarios. Here, a difference that a physicist would consider relatively small – initially at rest versus moving – caused major shifts in some students' mental models.

This study, thus, emphasizes the scenario in which a physics problem is presented is very important in determining the mental model which students apply. The data are not sufficient to discover any underlying reason for the effect of scenario on mental model.

5.3 *Does a student's correct application of Newton's Second Law reflect in course performance?*

Students with a high percentage of responses not inconsistent with Newton's Second Law achieved high and low final scores in both the first and second semester courses. The Wilcoxon matched-pairs signed-rank test showed that percentage of student responses not inconsistent with Newton's Second Law was not a predictor or indicator of student course performance for either the first semester or second semester courses. Perhaps more interestingly, the correlation was similarly poor in both semesters.

These data support the findings from other researchers (Cohen et al., 1978; McDermott, 1984; McDermott, 1991) that conceptual understanding does not reflect course performance. However, they strengthen the point because other investigations had not looked into differing contexts for student understanding. Conceptual understanding of Newton's Second Law is of little help with respect to achievement as assessed by traditional measures in introductory physics regardless of how well it is transferred to other contexts within the course.

5.4 *Recommendations for Further Study*

As with any investigation, more questions were found in the process of seeking answers to others. As mentioned in Section 4.3.5, some student responses to question in scenarios EF, EFV and BF indicated that the field would have more of an effect because the particle was larger and had more surface area to interact with the field. This misconception is currently being investigated from a different perspective by Rasil Warnakulasooriya (2001; 2003) at the Ohio State University.

Student responses to the first CH scenario question revealed difficulty with forces that diminish as $1/r^2$. Deeper investigation into this phenomenon may prove fruitful.

The data collected during this study also could be analyzed further. This investigation utilized student final answers. The processes that students employed in accepting and/or rejecting various ideas as they made their way to their final answers could be followed and analyzed from a cognition standpoint. Also, many questions that were asked were not used in this particular analysis. The student comparisons of homework problems and other contextual relations made by the students could be analyzed and investigated further.

5.5 *Implications for Instruction*

Research (Chi et al., 1981; Larkin et al., 1980) has shown that when novices and experts are presented with the same problem to solve, their responses differ because experts organize the needed information better than novices. To help students along the path towards mastery, inclusion of Newton's Second Law by explicitly showing how and where it is useful in other course topics would help delineate the boundary conditions of its use which are clear to experts but only to some novices. This clarification of boundary conditions may help expand students' contextual appreciation.

The student participants in this study were exposed to Newton's Second Law in other contexts via the interview questions. During the tutoring sessions that followed each interview, many students had 'aha' moments demonstrating a connection or clarification previously missed otherwise on their curricular path. These connections increased the students' awareness of the boundary conditions moving them towards mastery. Some of these questions could be posed to the students in class as part of the instructional process which would require little additional time. They may even be appropriate for use with an electronic response system.

The entire second semester had many variations in student's use of Newtonian-based mental models. The charge and field contexts triggered non-Newtonian models from students who otherwise provided consistent Newtonian responses. These scenario questions required the student to include Newton's second Law in ways that no other task in that portion of the course elicited. The introduction of mass into these problem scenarios troubled many students. They relied on equations since they had no first hand intuition regarding the subject. According to some students' logic, the equation of force in electricity and magnetism had no explicit mass component as Newton's Second Law does. Therefore, mass does not affect the motion in charge problems.

The student participants were not the only ones to have trouble with mass in the charge context. When testing a protocol, several graduate students and faculty members neglected gravity in response to a modified Millikan experiment scenario question until triggered with the fact the particle has mass. The boundary condition of including mass for delineating the choice to use Newton's Second Law or not then became clear.

Exposing this boundary condition during instruction would benefit student learning and unify understanding.

In addition to mass, the introduction of an initial velocity in charge and field scenarios caused some students to give non-Newtonian responses to questions. This velocity triggered both Aristotelian and Impetus type of mental models. Thus, velocity appears as a boundary condition to novices and not to experts. This initial velocity of a charge needs to be addressed separately and clearly in the second semester contexts.

The assumption of transference is most apparent in these findings from the wrench contextual scenario question. The assumption that a student will map the linear context easily to the rotational context is also reflected in textbooks. The textbook used by the students in this study offered only 17 homework problems that require Newton's Second Law in a rotational context as compared to 94 homework problems listed for a linear context (Halliday et al., 2001). For three recent instructors of this course at Kansas State University, the assigned problem ratio has been about four linear context problems for every rotational context, following the textbook's lead. That ratio reflects about four homework assignments in a linear context and one in rotational context. With respect to time, that means two weeks versus three days for a student to absorb these concepts.

Addressing rotational contexts as a separate domain instead of a tacit subset of mechanics would help the situation. Demonstrations and conceptual questions typically included with the introduction of a new concept would then be applied.

5.6 *Final Discussion*

The explicit or implicit assumption made by many instructors is that once a student has learned and understood a concept in one situation, she or he will then be able to apply it to another situation when required. This assumption of transference has been exposed as a poor one to make. Concept transfer to other contexts has been described as a process of learning called contextual appreciation. From the constructivist perspective learning takes effort. The student must construct the knowledge. In this case, the student must construct connections between concepts and contexts and vice versa.

This longitudinal investigation found that students do employ Newton's Second Law in contexts other than those used during the instruction of Newton's laws, but they are not consistent in doing so. The context and scenario affect students' choice of mental models when responding to questions that require Newton's Second Law. Each scenario investigated (rotation, simple harmonic motion, electric charges, electric and magnetic fields) was troublesome for some portion of the student participants. These results show that students are in different stages with respect to contextual appreciation of Newton's Second Law.

Students may increase their contextual appreciation with inclusion of Newton's Second Law topics throughout the course topics. The rotational, electric charge and field contexts appear to have especially weak connections to students' use of Newton's Second Law. Instruction including Newton's Second Law in these areas may help students expand their understanding of the boundary conditions for using this and other concepts in harmony.

CITED REFERENCES

Arzi, H. (1985). The long-term kinetics of conceptual development: The case of + = - and contextual differentation. *Research in Science Education, 15*, 112-121.

Atwater, M. M., Alick, B. E., Foley, L., Kight, C., & Smith, D. (1994). Bridging chemical problem solving and misconceptions in different contexts. In H. J. Schmidt (Ed.), *Problem solving and misconceptions in chemistry and physics - Proceedings of the 1994 International Seminar, University of Dortmund, Germany* (pp. 115-153). Hong Kong: International Council of Associations for Science Education.

Bagno, E., Eylon, B.-S., & Ganiel, U. (2000). From fragmented knowledge to a knowledge structure: linking the domains of mechanics and electromangetism. *American Journal of Physics, 68*(7), S16-S28.

Bao, L., Hogg, K., & Zollman, D. (2002). Model Analysis of Fine Structures of Student Models: An Example with Newton's Third Law. *American Journal of Physics, 20*(7), 766-778.

Barowy, W., & Lochhead, J. (1980). *Abstract Reasoning in Rotational Physics*. Amherst, MA: University of Massachusetts.

Bodner, G., & Klobuchar, M. (2001). The many forms of Constructivism. *Journal of Chemical Education, 78*(8), 1107. Also Available via the World Wide Web: http://chemed.chem.purdue.edu/chemed/bodnergroup/archive/publications/kelley.html

Bogdan, R., & Taylor, S. J. (1975). *Introduction to Qualitative Research Methods*. New York, New York: John Wiley and Sons.

Bogdan, R. C., & Biklen, S. K. (1998). *Qualitative Research in Education An introduction to Theory and Methods* (Third ed.). Needham Heights, Massachusetts: Allyn and Bacon.

Bone, D. D. (1983). *The development and evaluation of an introductory unit on circular functions and applications based on use of scientific calculators.* Unpublished Dissertation, Columbit University Teachers College, New York, NY.

Brennan, R. L. (1992). The context of context effects. *Applied Measurement in Education, 5*(3), 225-264.

Champagne, A. B., Klopfer, L. E., & Anderson, J. H. (1980). Factors influencing the learning of classical mechanics. *American Journal of Physics, 48*(12), 1074-1079.

Chi, M. T. h., Feltovich, P. J., & Glaser, R. (1981). Categorization and representation of Physics problems by experts and novices. *Cognitive Science, 5*, 121-152.

Chi, M. T. H., & roscoe, R. D. (2002). The processes and challenges of conceptual change. In M. Limón & L. Mason (Eds.), *Reconsidering Conceptual Change: Issues in Theory and Practice* (pp. 3-28). Dordrecht, the Netherlands: Kluwer Academic Publishers.

Chi, M. T. H., Slotta, J. D., & Leeuw, N. d. (1994). From things to processes: A theory of conceptual change for learning science concepts. *Learning and Instruction, 4*, 27-43.

Choi, J.-S., & Song, J. (1996). Students' Preferences for Different Contexts for Learning Science. *Research in Science Education, 26*(3), 341-352.

Clement, J. (1982). Students' preconceptions in introductory mechanics. *American Journal of Physics, 50*(1), 66-71.

Cobb, P. (1994). Constructivism in Mathematics and Science Education. *Educational Researcher, 23*(7), 4.

Cobern, W. W. (1993). Contextual constructivism: The impact of culture on the learning and teaching of science. In K. Tobin (Ed.), *The practice of constructivism in science education* (pp. 51-69). Washington, DC: AAAS Press.

Cohen, H. D., Hillman, D. F., & Agne, R. M. (1978). Cognitive level and college physics achievement. *American Journal of Physics, 46*(10), 1026-1029.

Creswell, J. W. (1998). *Qualitative inquiry and research design: Choosing among five traditions* (First ed.). Thousand Oaks, California: SAGE Publications, Inc.

Creswell, J. W. (2002). *Educational research: planning, conducting, and evaluating quantitative and qualitative research*. Upper Saddle River, New Jersey: Merrill Prentice Hall.

Cummins, D. D., Kintsch, W., Reusser, K., & Weimer, R. (1988). The role of understanding in solving word problems. *Cognitive Psychology, 20*, 405-438.

De Corte, E., Verschaffel, L., De Win, L. (1985). Influence of rewording verbal problems on children's problem representations and solutions. *Journal of Educational Psychology, 77*(4), 460-470.

deJong, T., & Ferguson-Hessler, M. G. M. (1996). Types and Qualities of Knowledge. *Educational Psychologist, 31*(2), 105-113.

Derry, S. J. (1996). Cognitive Schema Theory in the Constructivist Debate. *Educational Psychologist, 31*(3/4), 163-174.

Dictionary, M.-W. O. (2003). *"phenomenology"* [Website]. http://www.merriam-webster.com. Retrieved February 21, 2003, from the World Wide Web:

diSessa, A. A. (1982). Unlearning Aristotelian physics: A study of knowledge based learning. *Cognitive Science, 6*, 37-75.

diSessa, A. A. (2002). Why "conceptual ecology" is a good idea. In M. Limon & L. Mason (Eds.), *Reconsidering conceptual change: Issues in theory and practice* (pp. 29-60): Dortrecht: Kluwer.

Driver, R., Asoko, H., Leach, J., Mortimer, E., & Scott, P. (1994). Constructing Scientific Knowledge in the Classroom. *Educational Researcher, 23*(7), 5-12.

Ebison, M. G. (1993). Newtonian in Mind but Aristotelian at Heart. *Science & Education, 2*(4), 345-362.

Engel Clough, E., & Driver, R. (1986). A study of consistency in the use of students' conceptual frameworks across different task contexts. *Science Education, 70*(4), 24.

Engelhardt, P. V., & Rebello, S. (2003). *Ordering effects in multiple-choice exams and interviews.* Paper presented at the American Association of Physics Teachers National Meeting, Austin, Texas.

Erickson, G. (1994). Pupils' understanding magnetism in a practical assessment context: The relationship between content, process and progression. In P. Fensham, Gunstone, R. , White, R. (Ed.), *The content of science* (pp. 80-97). London: The Falmer Press.

Eryilmaz, A. (2002). Effects of Conceptual Assignments and conceptual Change Discussion on Students' Misconceptions and Achievement Regarding Force and Motion. *Journal of Research in Science Teaching, 39*(10), 1001-1015.

Fan, N., Mueller, J. H., & Marini, A. E. (1994). Solving Difference Problems: Wording Primes coordination. *Cognition and Instruction, 12*(4), 355-369.

Ferguson-Hessler, M. G. M., & Jong, T. d. (1987). On the quality of knowledge in the field of electricity and magnetism. *American Journal of Physics, 55*(6), 492-497.

Finegold, M., & Gorskey, P. (1991). Students' concepts of force as applied ot related physical systems: A search for consistency. *International Journal of Science Education, 13*(1), 97-113.

Fishbane, P. M., Gasiorowicz, S., & Thornton, S. T. (1996). *Physics for scientists and Engineers* (Second ed.). Upper Saddle River, New Jersey: Prentice Hall.

Galili, I. (1995). Mechanics background influences students' conceptions in electromagnetism. *International Journal of Science Education, 17*(3), 371-387.

Galili, I., & Bar, V. (1992). Motion implies force: where to expect vestiges of the misconception. *International Journal of Science Education, 14*(1), 63-81.

Gentner, D., & Stevens, A. L. (1983). *Mental Models*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Giannetto, E. (1993). The impetus Theory: Between history of physics and science education. *Science & Education, 2*(4), 227-238.

Glasersfeld, E. v. (1988). *Cognition, Construction of Knowledge, and Teaching*. Washington, DC: National Science Foundation.

Glasersfeld, E. v. (1995). *Radical Constructivism: A way of knowing and learning* (Vol. 6). Bristol, PA: Falmer Press, Taylore and Francis, Inc.

Gray, K., Rebello, S., & Zollman, D. A. (2003). *The Effect of Question Order on Responses to Interview Questions*. Paper presented at the American Association of Physics Teachers National Meeting, Austin, Texas.

Greca, I. M., & Moreira, M. A. (1997). The kinds of mental representations-models, propositions and images-used by college physics students regarding the concept of field. *International Journal of Science Education, 19*(6), 711-724.

Greca, I. M., & Moreira, M. A. (2002). Mental, physical, and mathematical models in the teaching and learning of physics. *Science Education, 86*(1), 106-121.

Hake, R. R. (1998). Interactive-engagement vs traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. *American Journal of Physics, 66*(1), 64-74.

Halldén, O. (1990). Questions asked in common sense contexts and in scientific contexts. In P. L. Lijnse, Licht, P. , Vos, W. de, Waarlo, A. J. (Ed.), *Relating macroscopic phenomena to microscopic particles: a central problem in secondary science education* (pp. 119-130). Utrecht: CD-ß Press.

Halldén, O. (1999). Conceptual change and contextualization. In W. Schnotz, Vosniadou, and Carretero (Ed.), *New perspectives on conceptual change* (Vol. 1, pp. 53-66;291-292). Kidlington,Oxford, UK: Elsevier Science Ltd.

Halliday, D., Resnick, R., & Walker, J. (2001). *Fundamentals of Physics - Extended* (Sixth ed.). New York: John Wiley and Sons, Inc.

Halloun, I. A., & Hestenes, D. (1985). Common-sense concepts about motion. *American Journal of Physics, 53*(11), 1056-1065.

Hammer, D. (2000). Student resources for learning introductory physics. *American Journal of Physics, Physics Education Research Supplement, 68*(S1), S52-S59.

Hestenes, D., Wells, M., & Swackhamer, G. (1992). Force concept inventory. *The Physics Teacher, 30*(3), 141-166.

Huffman, D., Heller, P. (1995). What does the force concept inventory actually measure? *The Physics Teacher, 33*(3), 138-143.

Jacob, E. (1987). Qualitative Research Traditions: A review. *Review of Educational Research, 57*(1), 1-50.

Kearney, M. D. (2002). *Classroom Use of multimedia-supported Predict-observe-explain tasks to elicit and promote discussion about students' physics conceptions.* Unpublished Dissertation, Curtin University of Technology, Curtin.

Klaczynski, P. A. (1994). Cognitive development in context: An investigation of practical problem solving and developmental tasks. *Journal of Youth & Adolescence, 23*(2), 141-168.

Krathwohl, D. R. (1998). *Methods of educational & social science research : an integrated approach*. New York, NY: Longman.

Kuhn, T. S. (1970). *The structure of scientific revolutions* (Vol. 2). Chicago, IL: University of Chicago Press.

Lancy, D. F. (1993). *Qualitative Research in Education: An Introduction to the Major Traditions* (First ed.). White Plains, New York: Longman Publishing Group.

Larkin, J., McDermott, J., Simon, D. P., & Simon, H. A. (1980). Expert and Novice Performance in Solving Physics Problems. *Science, 208*(4450), 1335-1342.

Leary, L. F., & Dorans, N. J. (1985). Implications for altering the context in which text items appear: A historical perspetive on an immediate concern. *Review of Educational Research, 55*(3), 387-413.

LeBlanc, M. D. (1994). Using a computer simulation to determine linguistic demands in arithmetic word problem solving or Is the time right ro a database of word problems? *Paper presented as part of the Annual meeting of the American Educational Research Association (AERA), New Orleans.*

Lin, H. (1982). Learning physics vs. passing courses. *The Physics Teacher, 20*(3), 151-157.

Linder, C. J. (1993a). A challenge to conceptual change. *Science Education, 77*(3), 293-300.

Linder, C. J. (1993b). *Characterization of meaningful learning: Conceptual change or contextual appreciation?* Paper presented at the Proceedings of the Third International Seminar on Misconceptions and Educational Strategies in Science and Mathematics, Ithaca, New York.

Maloney, D. P. (1985). Charged Poles? *Physics Education, 20*, 310-316.

Marshall, C., & Rossman, G. B. (1999). *Designing Qualitative Research 3rd Edition*. Thousand Oaks, California: SAGE Publications, Inc.

McCloskey, M. (1983a). Intuitive Physics. *Scientific American, 248*, 122-130.

McCloskey, M. (1983b). Naive theories of motion. In D. Gentner & A. L. Stevens (Eds.), *Mental models* (pp. 299-324). Hillsdale and London: Lawrence Erlbaum.

McCracken, G. (1988). *The Long Interview* (first ed. Vol. 13). Newbury Park, California: SAGE publications, Inc.

McDermott, L. C. (1983). Critical review of research in the domain of mechanics. *Research on Physics Education. Proceedings of the first international workshop. La Londe les Maures*, 139-182.

McDermott, L. C. (1984). Research on conceptual understanding in mechanics. *Physics Today, 37*(7), 24-32.

McDermott, L. C. (1991). Millikan lecture 1990: What we teach and what is learned: Closing the gap. *American Journal of Physics, 59*(4), 301-315.

McDermott, L. C., & Redish, E. F. (1999). Resource Letter: PER-1: Physics Education Research. *American Journal of Physics, 67*(9), 755-767.

McKinnon, J. W., & Renner, J. W. (1971). Are colleges concerned with intellectual development? *American Journal of Physics, 39*(9), 1047-1052.

McMillan, C. I., & Swadener, M. (1991). Novice use of qualitative versus quantitative Problem solving in Electrostatics. *Journal of Research in Science Teaching, 28*(8), 661-670.

Meacham, S. J. (2001). Vygotsky and the Blues: Re-Reading cultural connections and conceptual development. *Theory into practice, 40*(3), 190-197.

Medin, D. L., & Shoben, E. J. (1988). Context and Structure in Conceptual Combination. *Cognitive Psychology, 20*(2), 158-190.

Merton, R. K., Fiske, M., & Kendall, P. L. (1990). *The Focused Interview A manual of problems and procedures* (Second ed.). New York, NY: The Free Press.

Millar, R., & Kragh, W. (1994). Alternative frameworks or context-specific reasoning? Children's ideas about the motion of projectiles. *School Science Review, 75*(272), 27-34.

Minstrell, J. (1992). Facets of students' knowledge and relevant instruction. In R. Duit, Goldberg, F. , Niedderer, H. (Ed.), *Research in physics learning: Theoretical issues and empirical studies* (pp. 110-128). Kiel: IPN.

Mortimer, E. F. (1995). Conceptual Change or Conceptual Profile Change? *Science & Education, 4*, 267-285.

Munby, H., & Russell, T. (1998). Epistomology and context in research on learning to teach science. In B. J. Fraser, Tobin, K. G. (Ed.), *International handbook of science education, Part 2* (pp. 643-666). Dordrecht, The Netherlands: Kluwer Academic Publishers.

Norman, D. A. (1983). Some Obervations on Mental Models. In D. Gentner & A. L. Stevens (Eds.), *Mental Models* (pp. 7-14). Hillsdale, NJ: Lawrence Erlbaum Associates.

Ortiz, L. G. (2001). *Identifying and Addressing student difficulties with rotational dynamics.* Unpublished Dissertation, University of Washington.

Palmer, D. (1997). The effect of context on students' reasoning about forces. *International Journal of Science Education, 19*(6), 681-696.

Patton, M. Q. (1980). *Qualitative Evaluation Methods*. Beverly Hills, CA: SAGE Publications.

Patton, M. Q. (1983). *Qualitative Evaluation Methods* (Fifth Printing ed.). Beverly Hills, California: Sage Publications, Inc.

Patton, M. Q. (1990). *Qualitative evaluation and research methods*. Newbury Park, CA: SAGE Publications.

Perkins, D. N., & Salomon, G. (1998). Teaching for Transfer. *Educational Leadership, 46*, 22-32.

Peters, P. C. (1982). Even honors students have conceptual difficulties with physics. *American Journal of Physics, 50*(6), 501-508.

Phillips, D. C. (1995). The good, the bad, and the ugly: The many faces of Constructivism. *Educational Researcher*, *24*(7), 5-12.

Piaget, J. (1970). *Genetic epistemology* (E. Duckworth, Trans.). New York, NY: Columbia University Press.

Pozo, J.-I., Gomez, M.-A., & Sanz, A. (1999). When change does not mean replacement: Different representations for different contexts. In W. Schnotz, Vosniadou, and Carretero (Ed.), *New perspectives on conceptual change* (Vol. 1, pp. 161-174;302). Kidlington, Oxford, UK: Elsevier Science Ltd.

Rebello, N. S., Itza-Ortiz, S. F., & Zollman, D. A. (2003). *Students' mental models of Newton's Second Law: Mechanics to Electromagnetism.* Paper presented at the National Association of Science Teachers National Meeting, Philadelphia, PA.

Rebello, N. S., Zollman, D. A. (2003). The effect of distracters on student performance on the Force Concept Inventory. *American Journal of Physics, In Print*.

Redish, E. F. (1994). Implications of cognitive studies for teaching physics. *American Journal of Physics*, *62*(9), 796-803.

Rennie, L. J., & Parker, L. H. (1996). Placing physics problems in real-life context: Students' reactions and performance. *Australian Science Teachers Journal*, *42*(1), 55-59.

Reusser, K. (1990). Understanding word arithmetic problems: Linguistic and situational factors. *paper presented as part of the Annual meeting of the American Educational Research Association (AERA), Boston, April 16-20, 1990*.

Saul, J. M. (1998). *Beyond Problem-Solving: Evaluating Introductory Physics Courses Through the hidden Curriculum (Learning Expectations).* Unpublished Dissertation, University of Maryland, College Park, Maryland.

Savelsbergh, E. R., Jong, T. d., & Ferguson-Hessler, M. G. M. (2002). Situational Knowledge in Physics: The case of electrodynamics. *Journal of Research in Science Teaching*, *39*(10), 928-951.

Sears, F. w., Zemansky, M. W., & Young, H. D. (1983). *University Physics* (Sixth ed.). Reading, MA: Addison-Wesley Publishing Company.

Seidman, I. (1998). *Interviewing as Qualitative Research* (Second ed.). New York: Teachers College Press.

Smith, J. P., & diSessa, A. A. (1993). Misconceptions reconceived: A constructivist analysis of knowledge in transition. *The Journal of the Learning Sciences, 3*(2), 115-163.

Staver, J. (1998). Constructism: Sound theory for explicating the practice of science and science teaching. *Journal of Research in Science Teaching, 35*(5), 501-520.

Steinberg, M., Brown, D. E., & Clement, J. (1990). Genius is not immune to persistent misconcpetions: Conceptual difficulties impedig Isaac Newton. *International Journal of Science Education, 12*, 265.

Thornton, R. K., & Sokoloff, D. R. (1998). Assessing Student Learning of Newton's Laws: The force and Motion Conceptual Evaluation and the evaluaion of active Learning Laboratory and Lecture course. *American Journal of Physics, 66*(4), 338-352.

Törnkvist, S., Pettersson, K.-A., & Tranströmer, G. (1993). Confusion by representation: On student's conprehension of the electric field concept. *American Journal of Physics, 61*(4), 335-338.

Trowbridge, D. E., & McDermott, L. C. (1981). Investigation of student understanding of the concept of acceleration in one dimension. *American Journal of Physics, 49*, 242-253.

Vérillon, P. (2000). Revisiting Piaget and Vygotsky: In search of a Learning model for technology Education. *Journal of Technology Studies, 26*(1), 3-10.

Vosniadou, S. (1999). Conceptual Change Research: State of the Art and Future Directions. In S. V. Wolfgang Schnotz, & Mario Carretero (Ed.), *New Perspectives on Conceptual Change* (Vol. 1, pp. 3-13;284-285). Kidlington, Oxford, UK: Elsevier Science Ltd.

Vygotsky, L. (1986). *Thought and Language* (E. H. a. G. Vakar, Trans.). Cambridge, MA: MIT Press.

Wandersee, J. H., Mintzes, J. J., & Novak, J. D. (1994). Research on alternative conceptions in science. In D. Gabel (Ed.), *Handbook of research on science teaching and learning* (pp. 177-210). New York: Macmillan.

Warnakulasooriya, R., & Bao, L. (2001). *Preliminary studies on students' understanding of electricity and magnetism for the development of a model based diagnostic instrument*. Paper presented at the Physics Education Research Conference, Rochester, New York.

Warnakulasooriya, R., & Bao, L. (2003). *Contexts and Mental Models in Some topics of Electricity and Magnetism.* Paper presented at the 126th American Association of Physics Teacher National Meeting, Austin, Texas.

Whitaker, R. J. (1983). Aristotle is not dead: student understanding of trajectory motion. *American Journal of Physics, 51*(4), 352-357.

Wiggins, G. (1993). Assessment: Authenticity, context and validity. *Phi Delta Kappan, 75*(3), 200-214.

Wolfson, R., & Pasachoff, J. M. (1995). *Physics with Modern Physics for Scientists and engineers* (Second ed.). New York, NY: Harper Collins College Publishers.

Zollman, A. (1987). Aspects of transfer of learning in mathematical problem solving with respect to the order of problem presentation. *paper presented as part of the Annual meeting of the American Educational Research Association (AERA), Washington, DC, April 20-24, 1987*.

APPENDIX A

Interview Protocols

Interview Protocol for EPI – Interview 1: Introduction, Interest and Motivation

Student Name: ____

Present Informed consent and ask regarding audiotape recording.

What is your Major?

What made you choose this as your field of study? What interests you about it?

During the course there will be several objects and scenarios in your homework, studio activities, and on your quizzes. How familiar are you with the following:

1	3	5
Not at all	Somewhat	Quite Familiar

Space	1	3	5	
Rockets	1	3	5	
Pulleys	1	3	4	
Blocks	1	3	5	
Crates	1	3	5	
Airplanes	1	3	5	
Cars	1	3	5	
Springs	1	3	5	
Particles	1	3	5	
Molecules	1	3	5	
Electricity	1	3	5	
Magnets	1	3	5	
Shooting guns	1	3	5	
Sports –				
sailing,	1	3	5	
parachuting	1	3	5	
baseball,	1	3	5	
skiing	1	3	5	

Just because something isn't familiar doesn't mean you aren't interested in it. How interested are you in the following:

1	3	5
Not at all	Somewhat	Quite Interested

Space		1	3	5
Rockets		1	3	5
Pulleys		1	3	4
Blocks		1	3	5
Crates		1	3	5
Airplanes		1	3	5
Cars		1	3	5
Springs		1	3	5
Particles		1	3	5
Molecules		1	3	5
Electricity		1	3	5
Magnets		1	3	5
Shooting guns		1	3	5
Sports –				
	sailing,	1	3	5
	parachuting	1	3	5
	baseball,	1	3	5
	skiing	1	3	5

What do you hope to get out of this Physics Course?

What are you doing to attain this?

Thank you. You've already done some homework. I'd like to ask you about some of the problems that were assigned (have student look in book on table):

In Chapter 5, Problems 3 and 7 were both assigned. Did you correctly answer both?

3E. Only two horizontal forces act on a 3.0 kg body. One force is 9.0 N, acting due east, and the other is 8.0 N, acting 62° north of west. What is the magnitude of the body's acceleration?

7P. There are two forces on the 2.0 kg box in the overhead view of Fig. 5-31 but only one is shown. The figure also shows the acceleration of the box. Find the second force (a) in unit-vector notation and as (b) a magnitude and (c) a direction. ssm

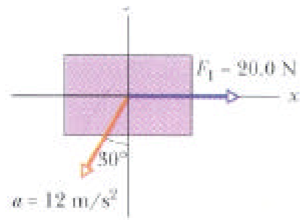


Fig. 5-31 Problem 7.

Was either problem harder?

Why or Why not?

Similarly, #17 and 20 were assigned (again have student look in book on table). Did you correctly answer both?

17E. *Sunjamming.* A "sun yacht" is a spacecraft with a large sail that is pushed by sunlight. Although such a push is tiny in everyday circumstances, it can be large enough to send the spacecraft outward from the Sun on a cost-free but slow trip. Suppose that the spacecraft has a mass of 900 kg and receives a push of 20 N. (a) What is the magnitude of the resulting acceleration? If the craft starts from rest, (b) how far will it travel in 1 day and (c) how fast will it then be moving?

20E. A car that weighs 1.30×10^4 N is initially moving at a speed of 40 km/h when the brakes are applied and the car is brought to a stop in 15 m. Assuming that the force that stops the car is constant, find (a) the magnitude of that force and (b) the time required for the change in speed. If the initial speed is doubled, and the car experiences the same force during the braking, by what factors are (c) the stopping distance and (d) the stopping time multiplied? (There could be a lesson here about the danger of driving at high speeds.)

Was either problem harder? Why?

Which was easier to visualize?

Take a look at number 5-42 (look in book on the table).

42P. A Navy jet (Fig. 5-40) with a weight of 231 kN requires an airspeed of 85 m/s for liftoff. The engine develops a maximum force of 107 kN, but that is insufficient for reaching takeoff speed in the 90 m runway available on an aircraft carrier. What minimum force (assumed constant) is needed from the catapult that is used to help launch the jet? Assume that the catapult and the jet's engine each exert a constant force over the 90 m distance used for takeoff.

Fig. 5-40 Problem 42.

Compare it to numbers 17 and 20.

Interview Protocol for EPI – Interview 2: Adding Friction and Constant Circular Motion
Chapter 5 and Chapter 6

Student Name: ____

Confirm audio tape recording acceptable

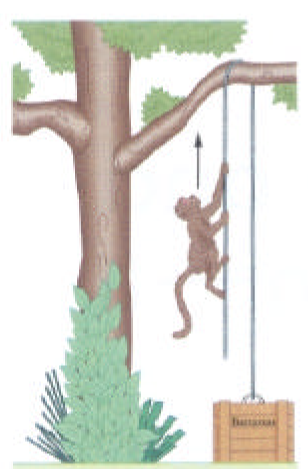
So how's it going?

How was the second exam?

Compare these two problems (student looks in book on the table):

5-40P. An 85 kg man lowers himself to the ground from a height of 10.0 m by holding onto a rope that runs over a frictionless pulley to a 65 kg sandbag. With what speed does the man hit the ground if he started from rest?

5-47P. A 10 kg monkey climbs up a massless rope that runs over a frictionless tree limb and back down to a 15 kg package on the ground (Fig. 5-43). (a) What is the magnitude of the least acceleration the monkey must have if it is to lift the package off the ground? If, after the package has been lifted, the monkey stops its climb and holds onto the rope, what are (b) the magnitude and (c) the direction of the monkey's acceleration, and (d) what is the tension in the rope'.? **ssm**



Did you correctly answer both questions?

Which was more difficult? Why?

Compare this problem to the previous two (again have student refer to book on table)

50P. Figure 5-46 shows a man sitting in a bosun's chair that dangles from a massless rope, which runs over a massless, frictionless pulley and back down to the man's hand. The combined mass of man and chair is 95.0 kg. With what force magnitude must the man pull on the rope if he is to rise (a) with a constant velocity and (b) with an upward acceleration of 1.30 m/s^2`? *(Hint:* A free-body diagram can really help.) Problem continues, next column. Suppose, instead, that the rope on the right extends to the ground, where it is pulled by a co-worker. With what force magnitude must the co-worker pull for the man to rise (c) with a constant velocity and (d) with an upward acceleration of 1.30 m/s^^2? What is the magnitude of the force on the ceiling from the pulley system in (e) part a (f) part b, (g) part c, and (h) part d?

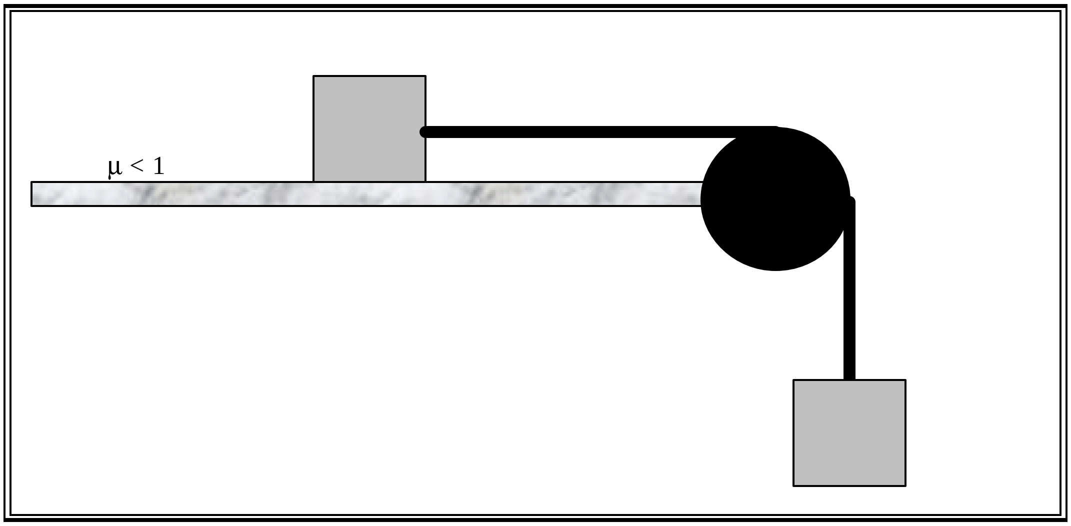
Fig. 5-46 Problem 50.

Which was more difficult? Why?

How did the Studio activity help your understanding of this problem?

Modified Atwood Machine:

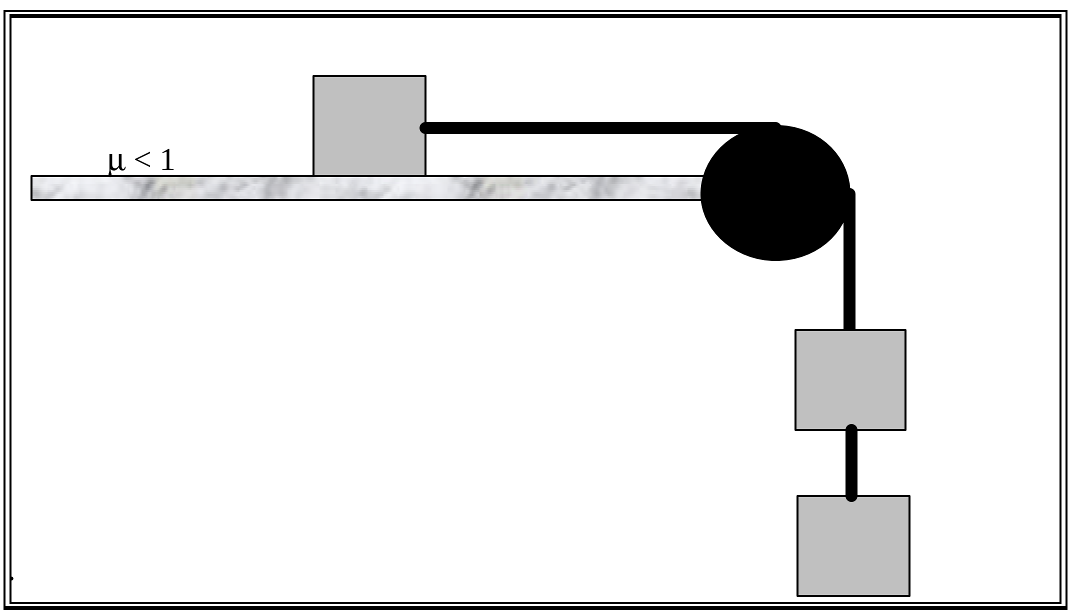
Show student the following image:



Describe the situation: The blocks are identical and the rope and pulley are considered to be massless. They are held in place and released. What happens?

Follow up: Describe the motion: Speeding up, slowing down, constant?

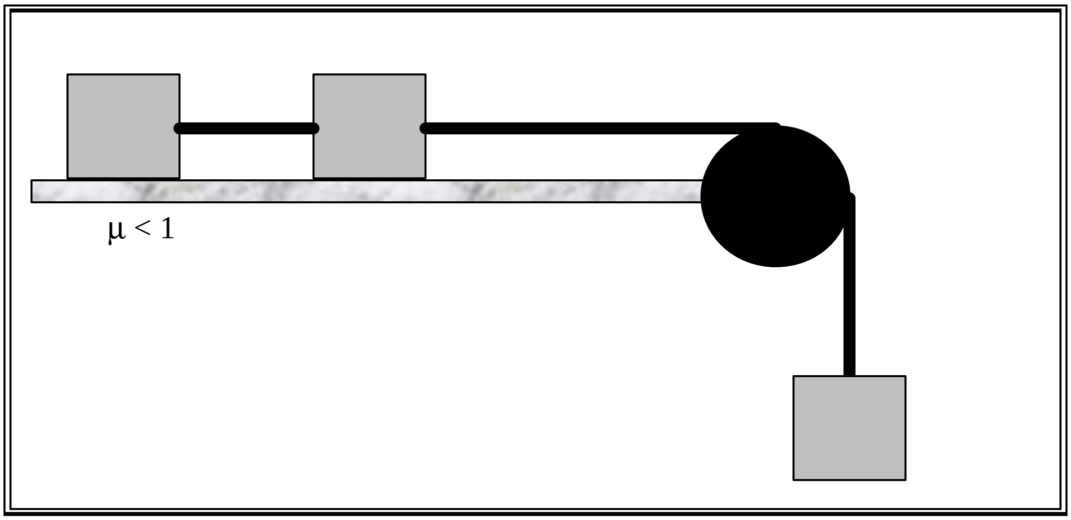
Show the student the following image:



Describe the situation: 3 identical masses are released from rest. What happens?

Follow up: Why? Compare to the previous case.

Show student the following image:



Describe the situation: 3 identical blocks released from rest. What happens?

Follow up: Why? Compare to previous cases.

3. Referring to image in front of the student with third identical block attached on table and released from rest. What happens?

Have student refer to these problems from the open book on the table:

5-43P. A block of mass m, = 3.70 kg on a frictionless inclined plane of angle 30.0° is connected by a cord over a massless, frictionless pulley to a second block of mass m_2 = 2.30 kg hanging vertically (Fig. 5-41). What are (a) the magnitude of the acceleration of each block and (b) the direction of the acceleration of the hanging block? (c) What is the tension in the cord? ssm itw www

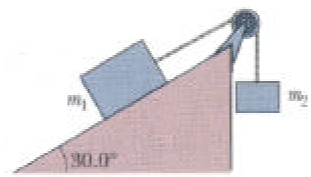


Fig. 5-41 Problem 43.

6-22P. In Fig. 6-31, two blocks are connected over a pulley. The mass of block A is 10 kg and the coefficient of kinetic friction between A and the incline is 0.20. Angle 0 of the incline is 30°. Block A slides down the incline at constant speed. What is the mass of block B?

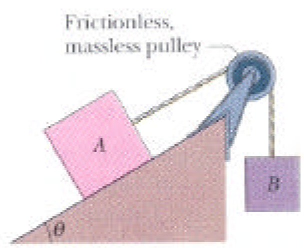


Fig. 6-31 Problems 21 and 22.

Did you correctly answer both questions?

Which was more difficult? Why?

Have student refer to these problems from the open book on the table:

5-31P. Two blocks are in contact on a frictionless table. A horizontal force is applied to the larger block, as shown in Fig. 5-35. (a) If m_1 = 2.3 kg, m_2 = 1.2 kg, and F = 3.2 N, find the magnitude of the force between the two blocks. (b) Show that if a force of the same magnitude F is applied to the smaller block but in the opposite direction, the magnitude of the force between the blocks is 2.1 N, which is not the same value calculated in (a). (c) Explain the difference. ssmitw

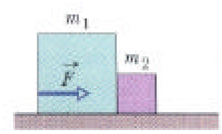


Fig. 5-35 Problem 31.

6-24P. In Fig. 6-32, a box of Cheerios and a box of Wheaties are accelerated across a horizontal surface by a horizontal force F applied to the Cheerios box. The magnitude of the frictional force on the Cheerios box is 2.0 N, and the magnitude of the frictional force on the Wheaties box is 4.0 N. If the magnitude of F is 12 N, what is the magnitude of the force on the Wheaties box from the Cheerios box?

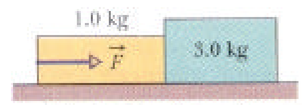


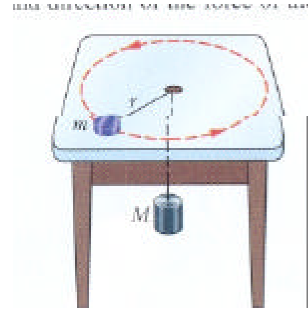
Fig. 6-32 Problem 24.

Did you correctly answer both questions?

Which was more difficult? Why?

6-37E. Suppose the coefficient of static friction between the road and the tires on a Formula One car is 0.6 during a Grand Prix auto race. What speed will put the car on the verge of sliding as it rounds a level curve of 30.5 m radius? Ssm

6-41P. A puck of mass m slides on a frictionless table while attached to a hanging cylinder of mass M by a cord through a hole in the table (Fig. 6-37). What speed keeps the cylinder at rest? ssm



Draw a free body diagram for the puck.

Interview Protocol for EPI – Interview 3: Systems of Particles
Chapter 9

Student Name: ____

Consent form completed?

Confirm audio tape recording acceptable.

So how's it going?

How was the 3rd exam?

Compare these two problems (student looks in book on the table):

15P. A shell is shot with an initial velocity v_0 of 20 m/s, at an angle of 60° with the horizontal. At the top of the trajectory, the shell explodes into two fragments of equal mass (Fig. 9-30). One fragment, whose speed immediately after the explosion is zero, falls vertically. How far from the gun does the other fragment land, assuming that the terrain is level and that air drag is negligible? ssm

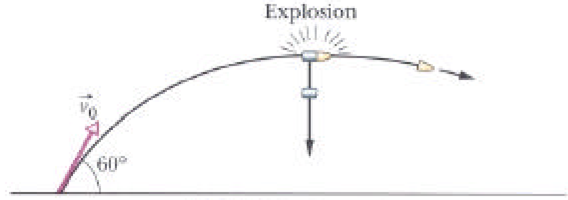


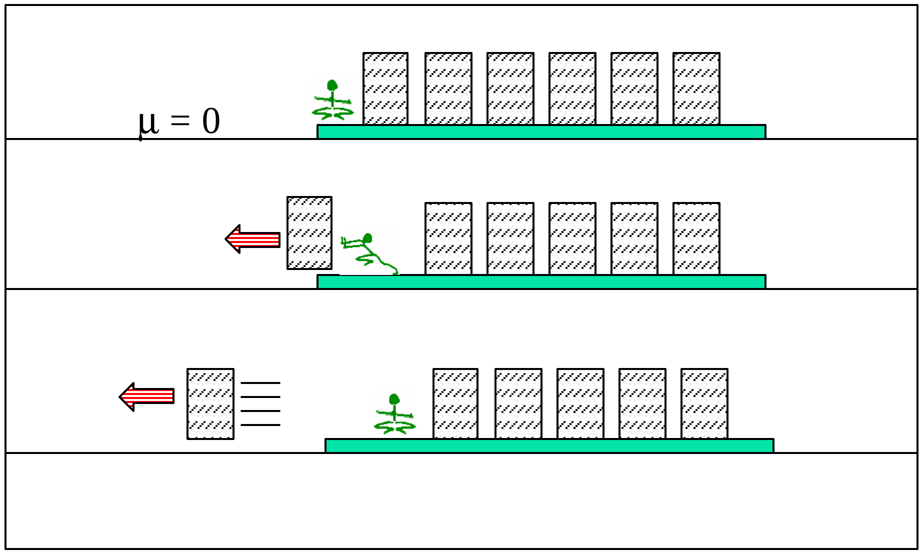
Fig. 9-30 Problem 15.

Did you correctly answer this question?

Was difficult?

Why or why not?

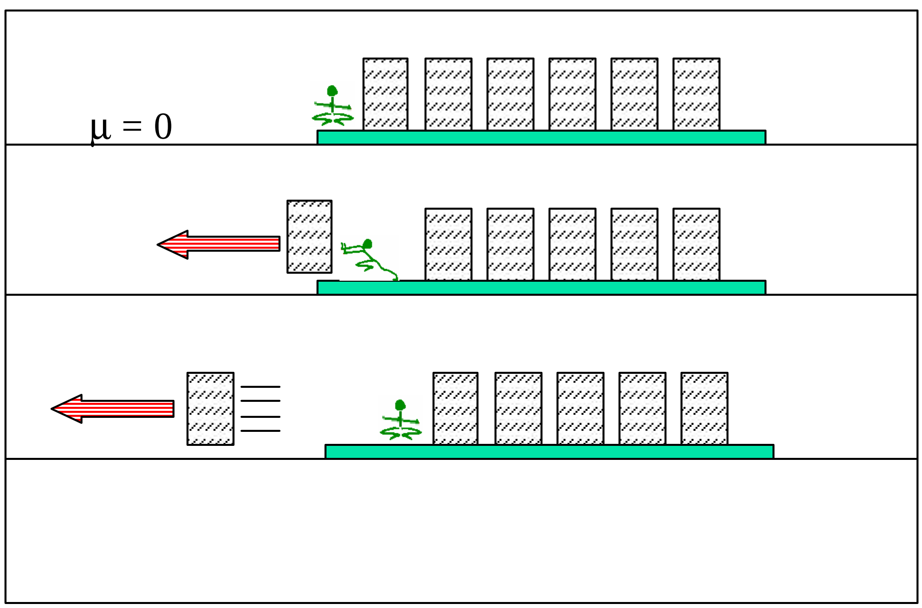
Show student the following image:



What happens with one mass expelled at velocity v?

Follow up: How or why is that happening

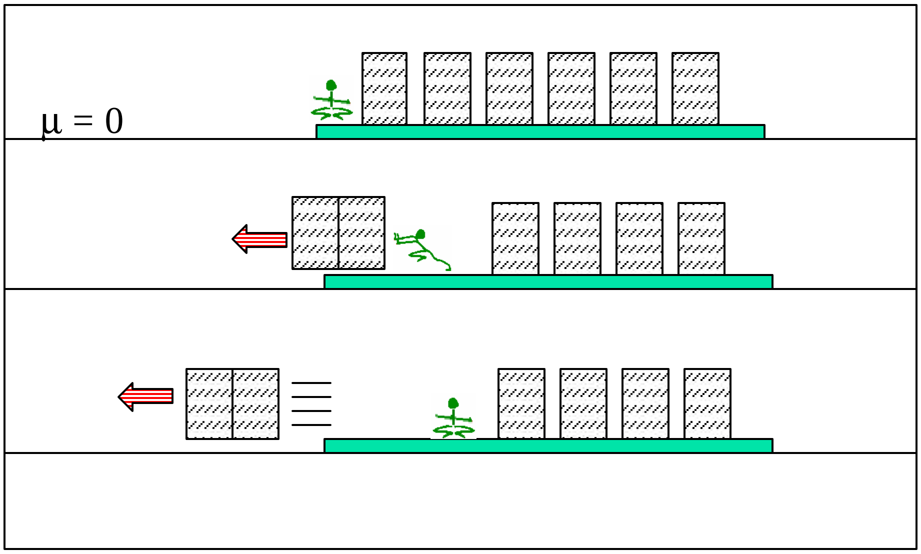
Show student the following image:



What happens when one mass expelled at twice the velocity?

Follow up: Compare to when one mass expelled at 2v.

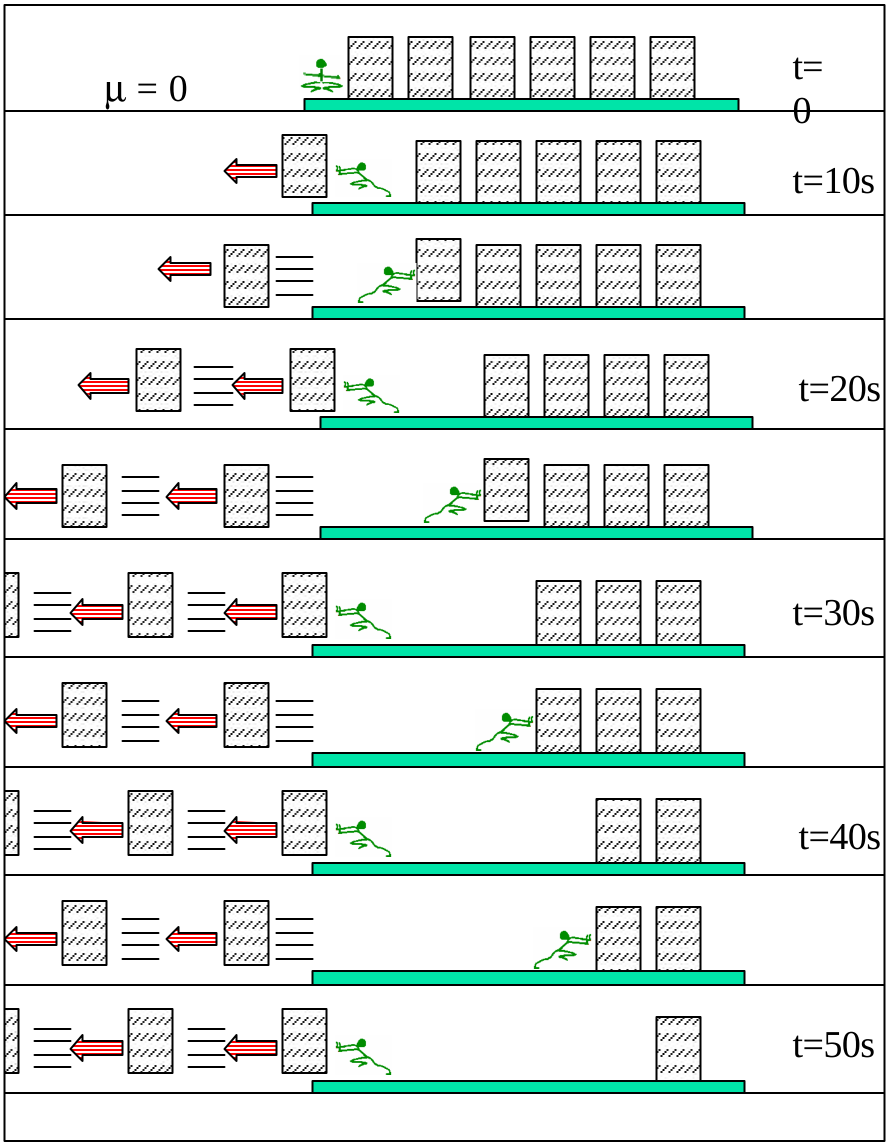
Show student the following image:



What happens when 2 masses are expelled at velocity v?

Follow up: Compare to original 1m at 1v case..

Show student the following image:



Describe the situation: A block is expelled at velocity v every 10 seconds. What is happening in this situation?

Follow up: Describe the motion of the sled?

Follow up: Is it increasing, decreasing, constant?

Follow up: Is the change in velocity from 10s to 20s the same as the change in velocity from 40s to 50s?

Follow up: If there's an increase in velocity, does that mean there's a force on it?

Follow up: If so, where did it come from?

I've shown this scenario to faculty and they have seen a similarity to a topic covered in this course. I don't expect you to necessarily agree – there are a number of factors involved. Can you relate this to something you have studied? This is a research project so please let me know if you are guessing.

With that stated, this is a problem that the faculty would associate with the assigned homework problem – refer student to problem 43E in book.

43E. A rocket, which is in deep space and initially at rest relative to an inertial reference frame, has a mass of 2.55×10^5 kg, of which 1.81×10^5 kg is fuel. The rocket engine is then fired for 250 s, during which fuel is consumed at the rate of 480 kg/s. The speed of the exhaust products relative to the rocket is 3.27 km/s. (a) What is the rocket's thrust? After the 250 s firing, what are (b) the mass and (c) the speed of the rocket? ssm ilw

Can you see a similarity now?

How so?

Interview Protocol for EPI – Interview 4: Rotation and SHO
Chapters 12 and 16

Student Name: ____

Confirm audio tape recording acceptable.

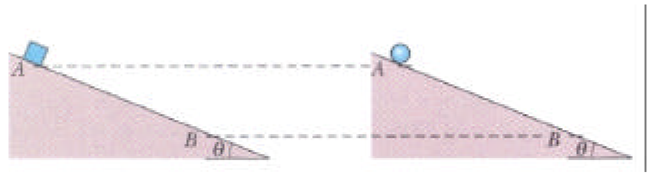
So how’s it going?

How were the last 2 exams?

Would you be interested in continuing next semester?

Inclined Plane Question (Large version of image on table):

Show student the following image:



Describe the situation: The block is on a frictionless surface and the ball rolls without slipping. Does either the block or sphere reach the bottom first?

Follow up: Why? Or Why not?

Follow up: Can you put that in terms of Forces?

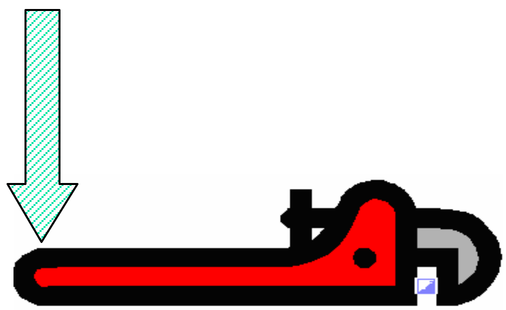
Wrench Problem

Show student the following image;

Describe the situation: A wrench is clamped onto a well greased pin. It is pushed with a constant force indicated by the arrow. What will happen?

Follow up: Describe the motion: constant, slowing down or speeding up?

Show the student the following image:

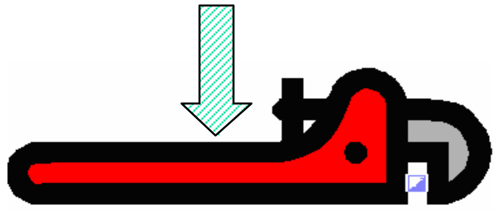


Describe the situation: The same wrench has twice the force applied to the end of it. What happens?

Follow up: Describe the motion: constant, slowing down or speeding up?

Follow up: Compare previous case.

Show student the following image;



Describe the situation: The same force as the original case is not applied half way up the wrench handle. What happens?

Follow up: Describe the motion: constant, slowing down or speeding up?

Follow up: Compare to original case.

Now let's look at # 16-16 (student looks at problem in the book on the table).

16P. In Fig. 16-28, two blocks (m = 1.0 kg and M = 10 kg) ands spring (k = 200 N/m) are arranged on a horizontal, frictionless surface. The coefficient of static friction between the two blocks is 0.40. What amplitude of simple harmonic motion of the spring - blocks system puts the smaller block on the verge of slipping over the larger block?

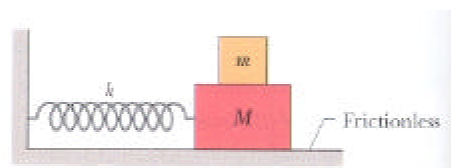


Fig. 16-28 Problem 16.

How would you set up this problem – what do you need to do to solve it?

Where would the block be most likely to slip?

Why?

And 16-18 (student looks at problem in book on table)

18P, A block rides on a piston that is moving vertically with simple harmonic motion. (a) If the SHM has period 1.0 s, at what amplitude of motion will the block and piston separate? (b) If the piston has an amplitude of 5.0 cm, what is the maximum frequency for which the block and piston will be in contact continuously?

How would you set up this problem?

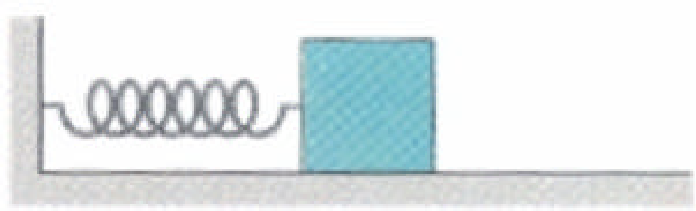
Which of these two (16 or 18) was more difficult to set up.

Why?

Do you see any similarities in these two problems?

Basic SHM questions

Show student the following image:



Describe the situation: A block attached to a spring on a frictionless surface. It is pulled out and released.

Does the force on the block vary or is it constant?

Follow up: Where is it a maximum?

Does the velocity of the block vary or is it constant?

Follow up: Where is it a maximum?

Does the acceleration of the block vary or is it constant?

Follow up: Where is it a maximum?

Interview Protocol for EPII – Interview 5: Electric Fields
Chapters 22 and 23

Student Name: ____

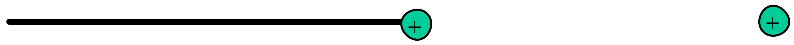
Remind student of Consent and voluntary participation or have fill out if not returning student.

So how's it going?

How was the exam?

How was your summer?

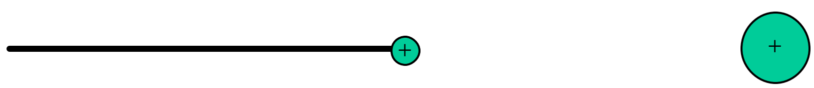
1. Show student the following image:



Describe the situation. There are 2 identical, particles, spheres, charges, blocks or whatever you would like to call them with a net charge of +. The one on the left is fixed and the one on the right is free to move. The one on the right is placed in position and released. What happens?

Follow up: Describe the motion – increasing, decreasing, constant, spinning, changing colors?

2. Now show the student the following image:



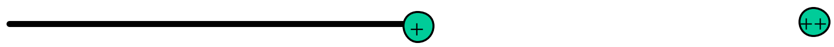
Describe the situation. Use student's definition of the objects. The one on the right is now twice as big. It is placed in position and released. What happens? Compare motion to previous case.

Follow up: If student misinterprets size as amount of charge, correct. It is twice as much of the same stuff. With the same net charge of +.

Follow up: Be sure student understands it is more massive than first case.

Follow up: Describe the motion – increasing, decreasing, constant, spinning, changing colors? Compare it to the first case.

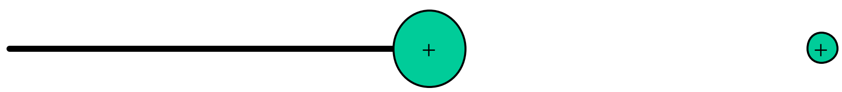
3. Show the student the following image:



Describe the situation. The one on the right now has twice the charge. It is placed into position and released. What happens? Compare to the first case.

Describe the motion – increasing, decreasing, constant, spinning, changing colors? Compare it to the first case.

4. Show the student the following image:

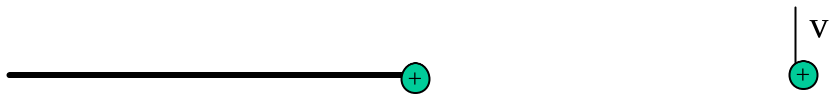


Describe the situation. The one on the left is not twice as big with identical charge. The one on the right is placed into position and released. What happens? Compare to first case.

Follow up: Describe the motion – increasing, decreasing, constant, spinning, changing colors? Compare it to the first case.

Follow up: How is that different than the second case?

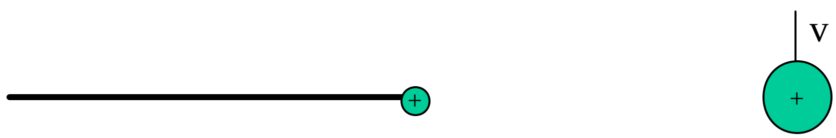
5. Show the student the following image:



Describe the situation. There are 2 identical, particles, spheres, charges, blocks or whatever you would like to call them with a net charge of +. The one on the left is fixed and the one on the right is free to move. They have been filmed and the film is stopped. At that time, the one on the right is going velocity, v, as indicated in the image. What happens when the film is started up again? Please draw the trajectory.

Follow up: Why is it moving in that manner?

6. Show student the following image:



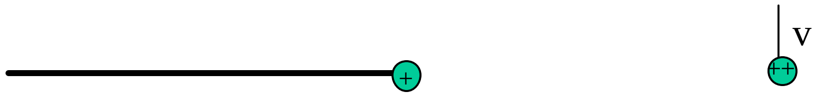
Describe the situation. Use student's definition of the objects. The one on the right is now twice as big. Its film is stopped as well with the one on the right going the same velocity as previously. What happens when the film is started up? Please draw the trajectory

Follow up: If student misinterprets size as amount of charge, correct. It is twice as much of the same stuff. With the same net charge of +.

Follow up: Be sure student understands it is more massive than first case.

Follow up: Compare motion to previous case.

7. Show student the following image:

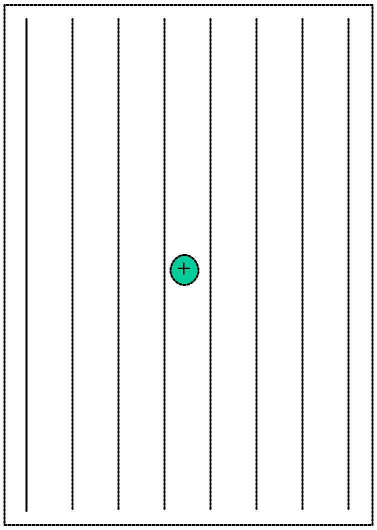


Describe the situation. The one on the right now has twice the charge. Its film is stopped with the one on the right going the same velocity, v, as previously. What happens when the film is started up? Please draw the trajectory.

Follow up: Compare to the first case.

Follow up: Describe the motion – increasing, decreasing, constant, spinning, changing colors? Compare it to the first case.

8. Show the student the following image:

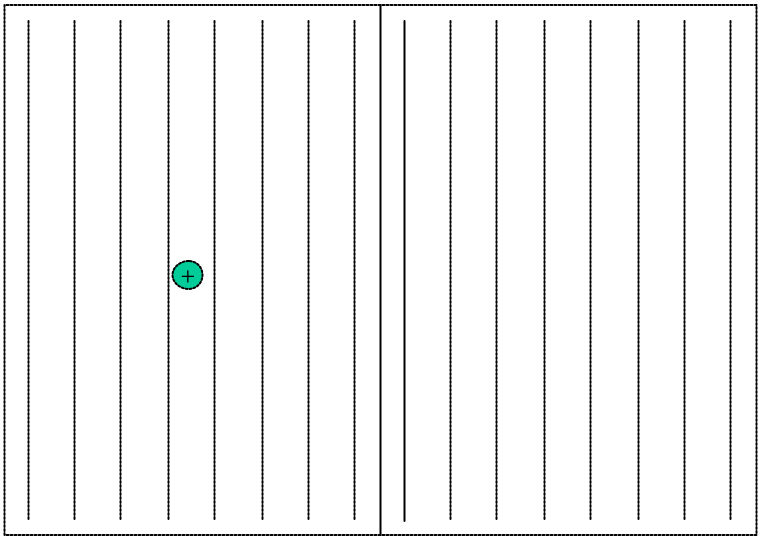


Describe the situation: The dotted line denotes a boundary of the electric field. It is not a barrier, just a line like a line on a football field. Inside the area is a constant electric field represented by the arrows which show it pointing towards the student. The charged particle (block, sphere, use what student called object) is placed into position and released. What happens?

Follow up: Describe the motion – increasing, decreasing, constant, spinning, changing colors?

Follow up: If student ignores boundary. Does it keep going like that?

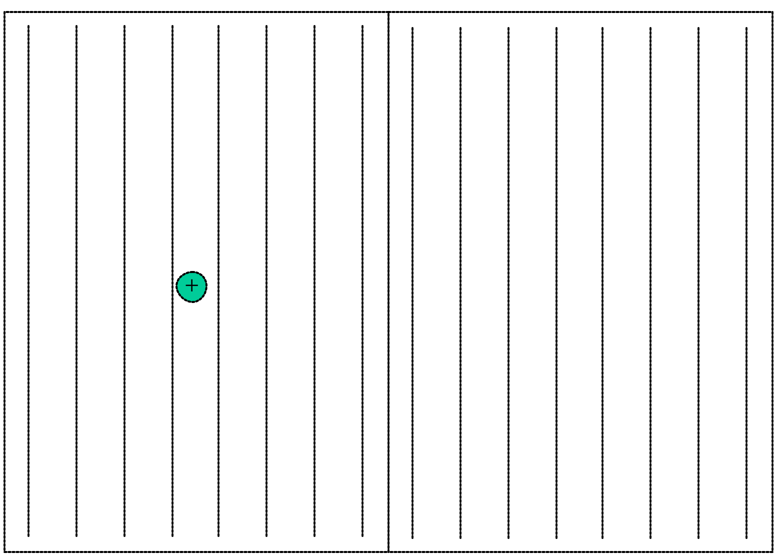
9. Show student the following image:



Describe the situation: Now I've taken the same field and added it on the right. The particle is placed into the same position and released. What happens?

Follow up: Compare to first case.

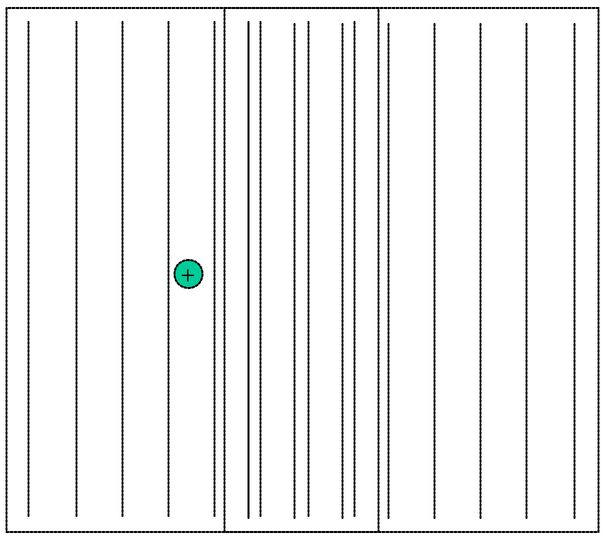
10. Show student the following image:



Describe the situation: Now I've taken the same field and added it on the right, but in the other direction. The particle is placed into the same position and released. What happens?

Follow up: Compare to first case.

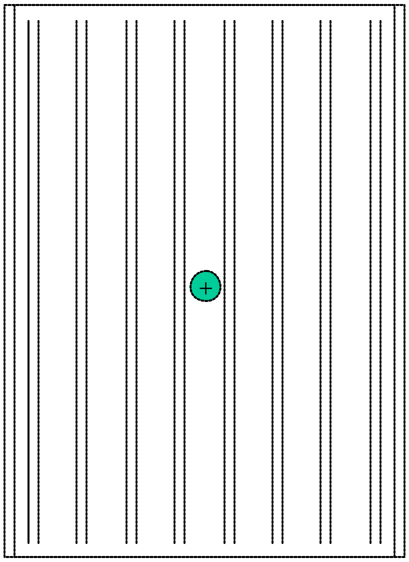
11. Show the student the following image:



Describe the situation: Now I've taken the added field on the right and moved it so it overlaps a bit. The particle is placed into the same position and released. What happens?

Follow up: Compare to first case.

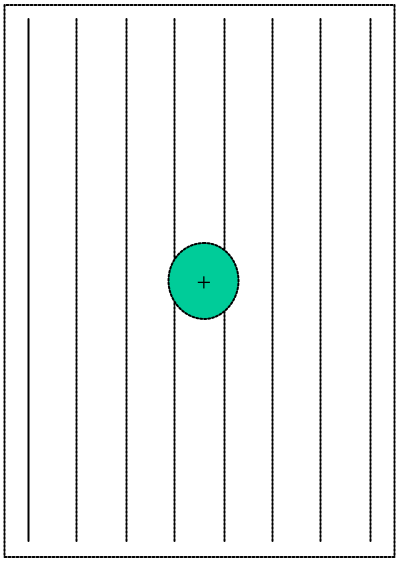
12. Show the student the following image:



Describe the situation: Now I've taken the added field on the right and moved it so it overlaps completely. The particle is placed into the same position and released. What happens?

Follow up: Compare to first case.

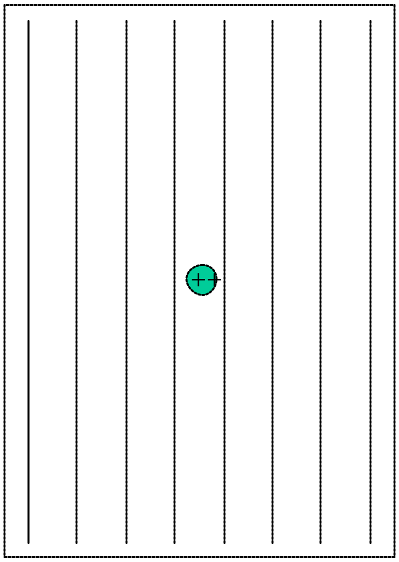
13. Show the student the following image:



Describe the situation: The charged particle (block, sphere, use what student called object) is now twice as big with the same charge. It is placed into position and released. What happens?

Follow up: Compare to original case.

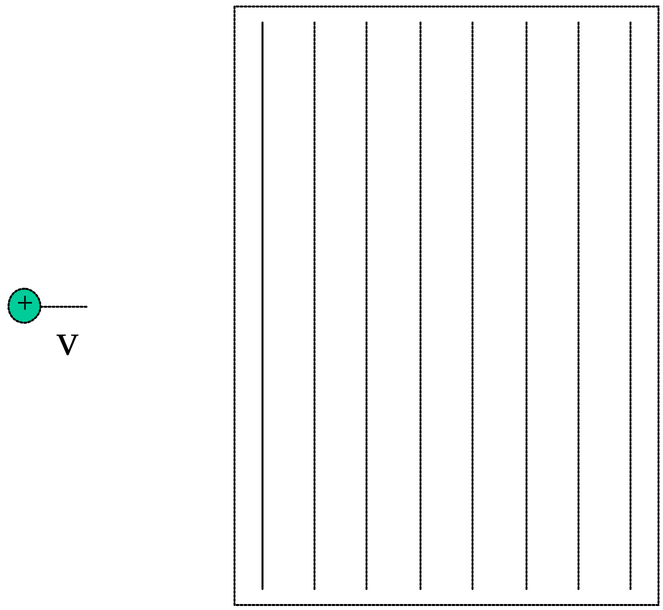
14. Show the student the following image:



Describe the situation: The charged particle (block, sphere, use what student called object) is now twice as big with the same charge. It is placed into position and released. What happens?

Follow up: Compare to original case.

15. Show the student the following image:

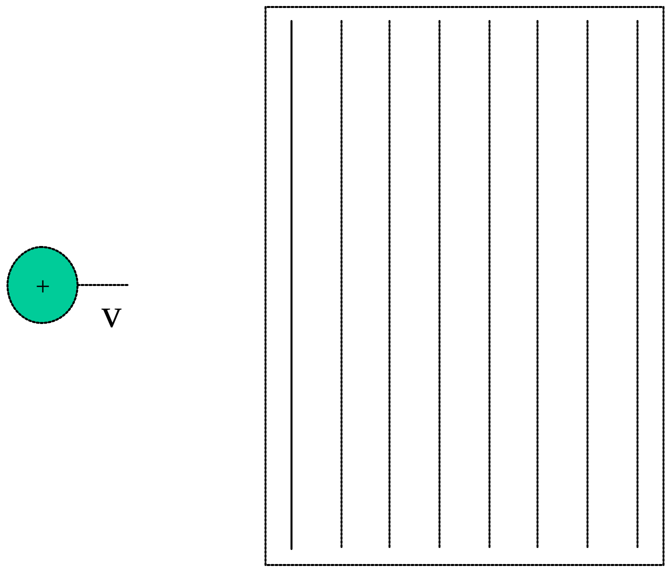


Describe the situation: The dotted line denotes a boundary of the electric field. It is not a barrier, just a line like on a football field. Inside the area is a constant electric field represented by the arrows which show it pointing towards the student. The charged particle (block, sphere, use what student called object) is moving towards the electric field with a velocity v. What happens? Please draw the trajectory.

Follow up: If student ignores boundary. Does it stop?

Follow up: What does it do out here?

16. Show student the following image:



Describe the situation: The charged particle (block, sphere, use what student called object) is now twice as big. It is moving towards the electric field with the same velocity as the previous one. What happens? Please draw the trajectory.

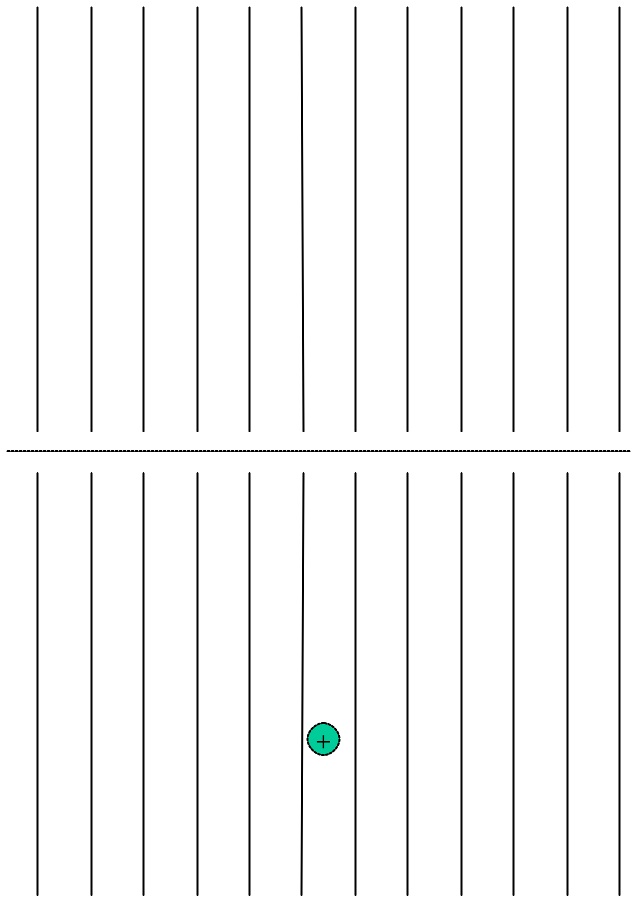
Follow up: If compare to first case.

17. Show the student the following image:

Describe the situation: The electric field is now pointing in a different direction. Inside the area is a constant electric field represented by the arrows which show it pointing towards the right. The charged particle (block, sphere, use what student called object) is moving towards the electric field with a velocity v. What happens? Please draw the trajectory.

Follow up: What does it do out here?

18. Show the student the following image:

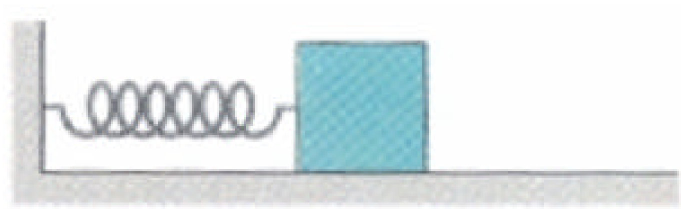


Describe the situation: There are two opposing electric fields separated by a dashed line. The boundary is not a barrier just a line like on a football field. The particle (use what student called the object) is placed into position and released. What happens?

Follow up: Have opposing field image available for field theory errors by the student.

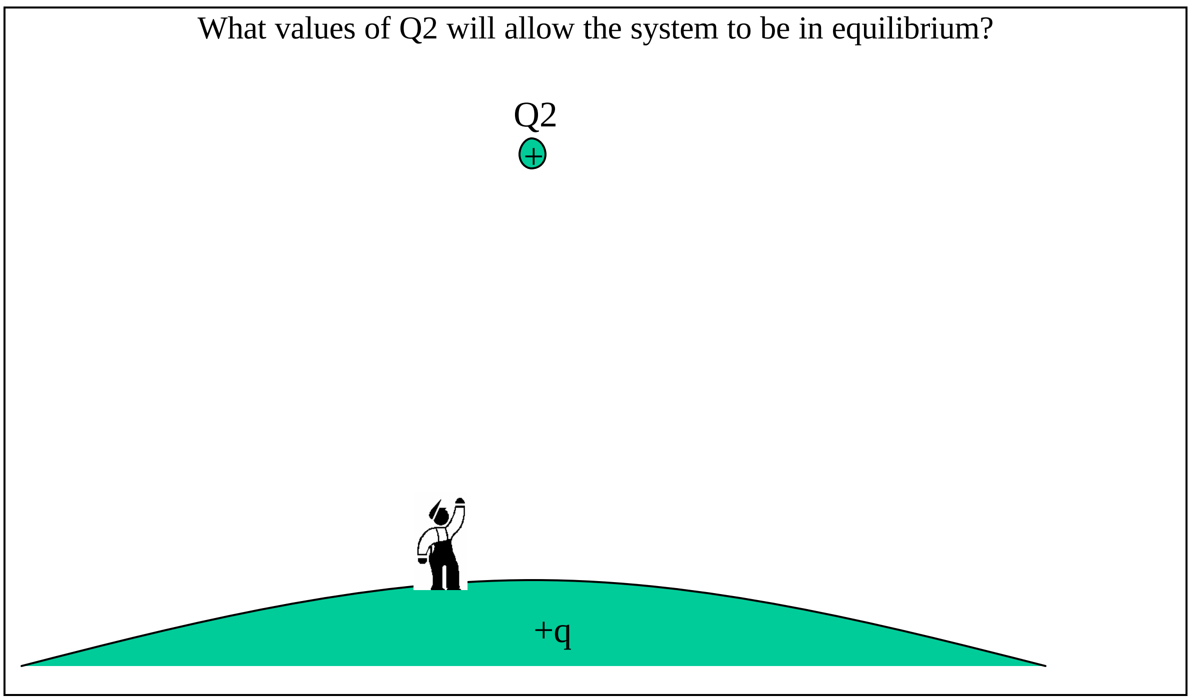
Follow up: How far does it go into this other field?

Follow up: If student doesn't see SHM – prompt to what faculty have thought – show the student the following image:



Do you see any similarities? What are they?

19. Show student the following image:

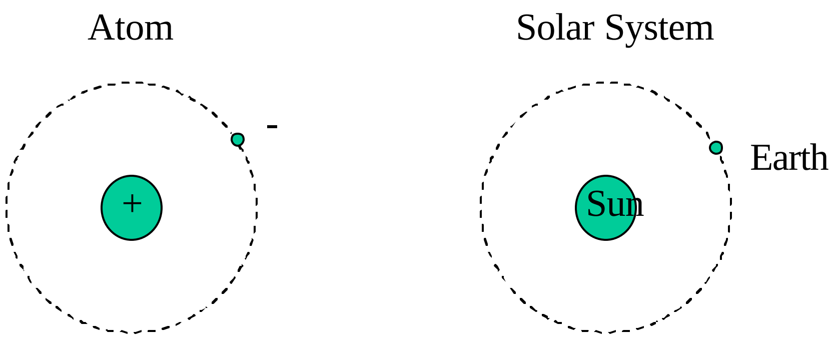


How would you go about solving this problem?

Follow up: Q2 is shown as positive only for easy sign convention.

Follow up: What if q has mass of 20 kg and Q2 has mass of 2 kg. Does that help?

20. Show the student the following image:



Describe the situation: Early in the last century a man by the name of Bohr described the atom as having a large positive charge in the center with a small negative charge orbiting in a nearly circular orbit. Since that time, it has been found to be an erroneous model but it still has some use. Similarly, the sun is a very large mass with the earth orbiting in t nearly circular orbit. Compare and contrast these situations.

Follow up: How are they similar?

Follow up: How are they different?

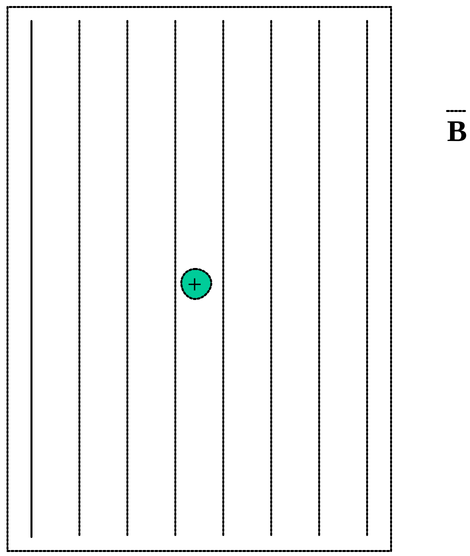
Interview Protocol for EPII – Interview 6: Magnetic Fields
Chapters 29 & 30

Student Name: ____

So how's it going?

How was the last exam?

1. Show the student the following image:

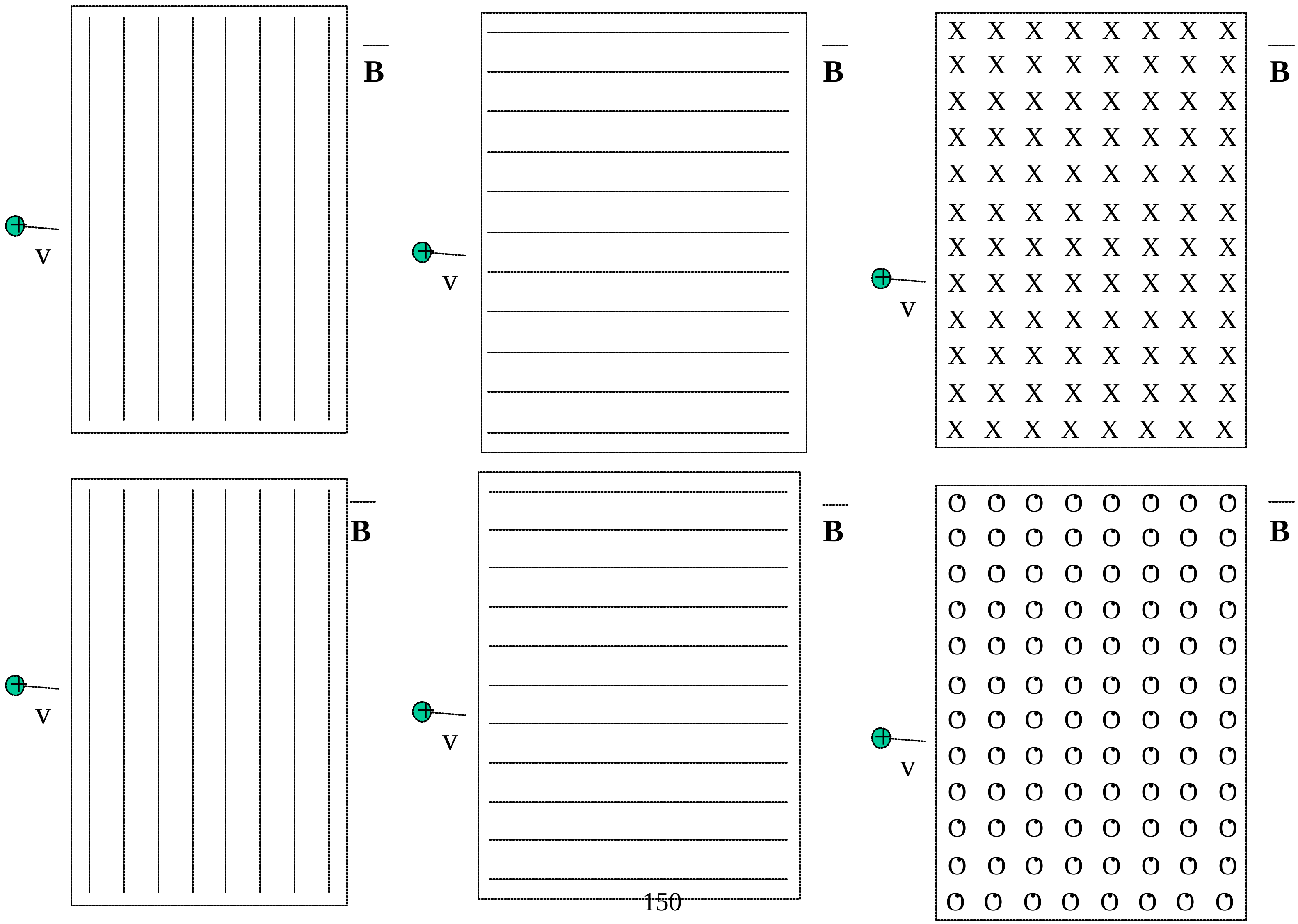


Describe the situation: The dotted line denotes a boundary of the magnetic field. It is not a barrier, just a line like a line on a football field. Inside the area is a constant magnetic field represented by the arrows which show it pointing towards the student. The B to the right is to remind you that this is a magnetic field as opposed to an electric field like the last interview. A charged particle, block, or sphere is placed into position and released. What happens?

Follow up: Describe the motion – increasing, decreasing, constant, spinning, changing colors?

Follow up: If student ignores boundary. Does it keep going like that?

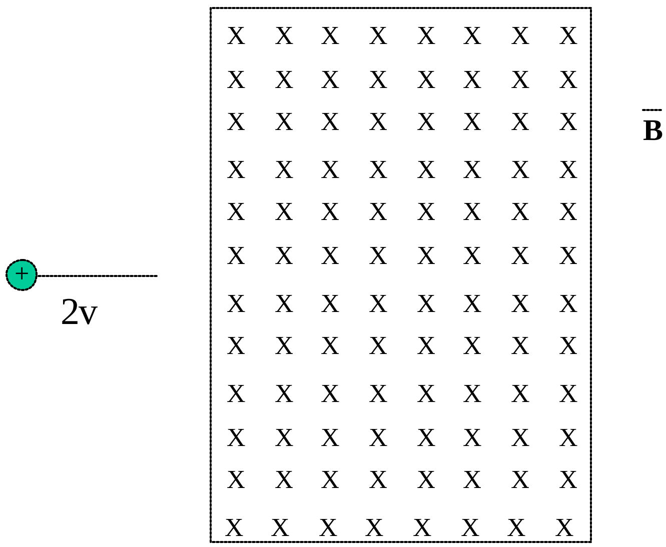
2. Show the student the six images on the next page. They are laid out in a similar manner.


B
v

Describe the situation: The charged particle (block, sphere, use what student called object) is now traveling with a velocity v, towards the magnetic field area. The only difference between scenarios is the direction of the magnetic field. It's either, up/dow, left/right or in/out. Please choose a scenario to draw what happens? Please draw the trajectory.

Follow up: Why did you choose this direction for the magnetic field?

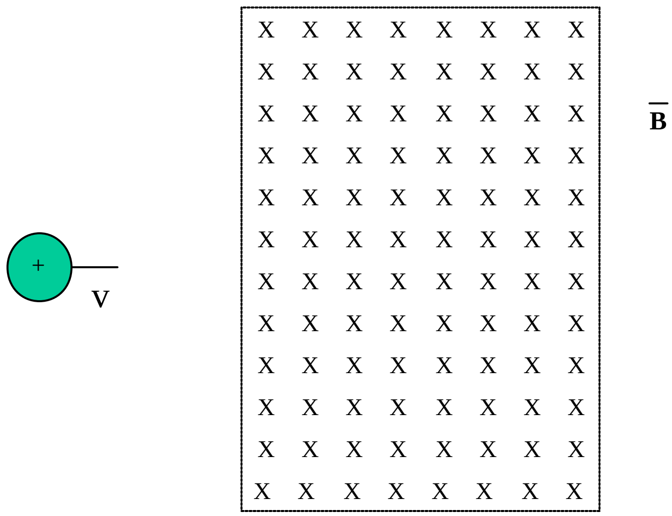
3. Show the student the next image based on which scenario she or he chose. The scenario IN is chosen as an example to carry through this protocol.



Describe the situation: The charged particle (use what student called object) is now moving at twice the velocity as the previous one. What happens? Please draw the trajectory.

Follow up: If compare to first case.

4. Show the student the following image:

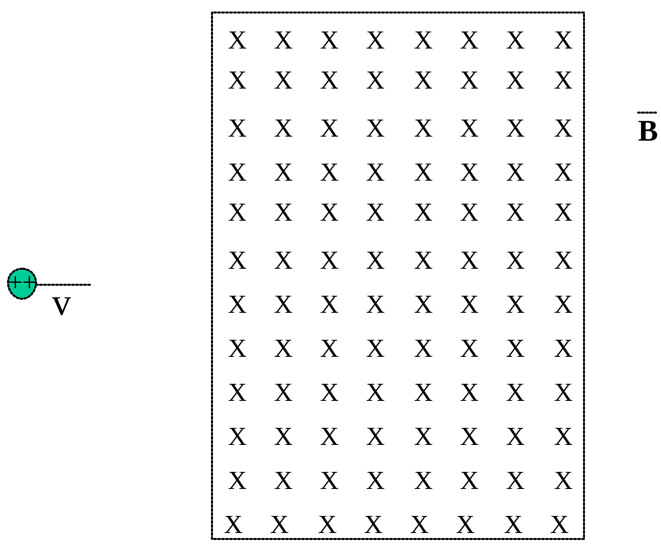


Describe the situation: The charged particle (use what student called object) is now twice as big. It is moving at the same velocity as the first case. What happens? Please draw the trajectory.

Follow up: If compare to first case.

Follow up: Be sure student understands it has more mass.

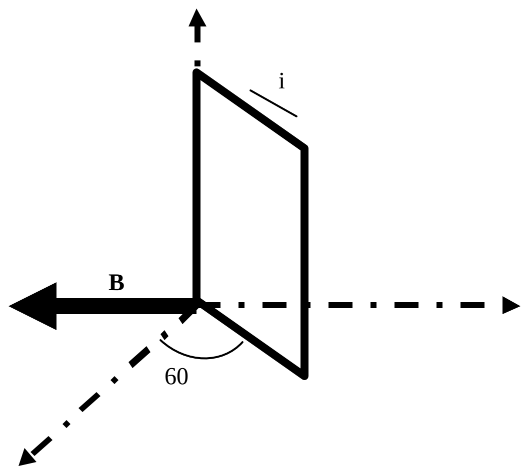
5. Show student the following image:



Describe the situation: The charged particle (use what student called object) is now has twice the charge. It is moving at the same velocity as the first case. What happens? Please draw the trajectory.

Follow up: If compare to first case.

6. Show student the following image:



Describe the situation: There is a rectangular loop carrying current, i. The dashed lines represent orthogonal coordinates of student's choice. One axis is conveniently aligned with one side of the loop. It is 60 degrees from the out of page direction. Describe what will happen and why?

7. Show student problem #35 from textbook:

> 35E. A wire of 62.0 cm length and 13.0 g mass is suspended by a pair of flexible leads in a uniform magnetic field of magnitude 0.440 T (Fig. 29-35). What are the magnitude and direction of the current required to remove the tension in the supporting leads? ssm ilw

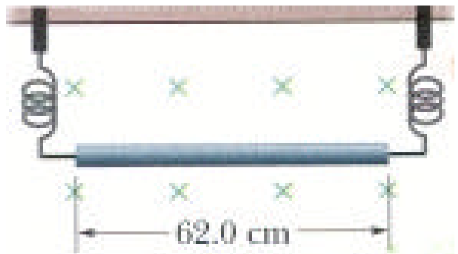
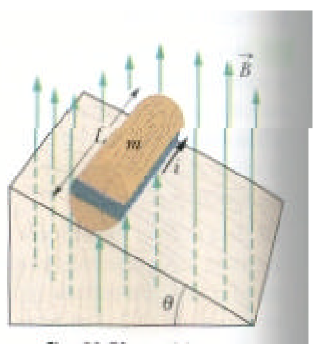


Figure 29-35

How would you go about solving this problem?

8. Show student problem 29-47 from the textbook:

> 47P. Figure 29-38 shows a wood cylinder of mass m = 0.250 kg and length 1, = 0.100 m. with N = 10.0 turns of wire wrapped around it longitudinally, so that the plane of tire wire coil contains the axis of the cylinder. What is the lead current that will prevent the cylinder from rolling down a plane inclined at an angle θ to the horizontal, in the presence of a vertical, uniform magnetic field of magnitude 0.500 T, if the plane of the coil is parallel to the inclined plane? ssm



Figure

This was one of your assigned homework problems. Do you remember it?

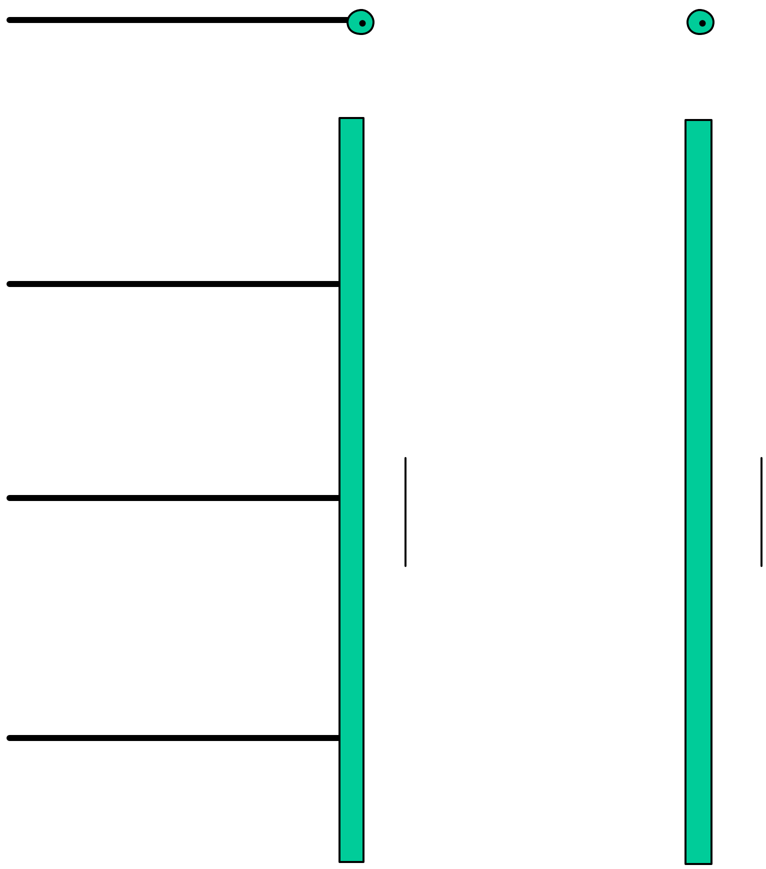
Follow up: Did you find it difficult?

Follow up: Why?

Follow up: Is there a similarity between this problem and the Current Loop question above?

Follow up: Why or why not?

9. Show the student the following images:



Describe the situation: There are two identical wires carrying the same current in the same direction. The one on the left is fixed and the one on the right is free. The upper image is the end view of the wires with the current coming out of the page while the lower image is the top view. If they were lying on the table and then the current turned on, what would happen?

10. How did our last interview influence your answer?

11. Have you changed majors?

Thank you for your time. Today is Payday.

Appendix B

Student Participant
Consent Forms

KANSAS STATE UNIVERSITY

INFORMED CONSENT

PROJECT TITLE:	Technology & Model-Based Conceptual Assessment: Research in Students' Application of Models in Physics & Mathematics
PRINCIPAL INVESTIGATOR: CO-INVESTIGATOR(S):	Dean Zollman 785-532-1619 (PI) Sanjay Rebello 785-532-1539 (Co PI) Alicia R. Allbaugh 785-532-7167
CONTACT AND PHONE FOR ANY PROBLEMS/QUESTIONS:	Dean Zollman dzollman@phys.ksu.edu 785-532-1619
IRB CHAIR CONTACT/PHONE INFORMATION:	Clive Fullagar, Chair of Committee on Researh involving Human Subjects 1 Fairchild Kansas State University, Manhattan KS, 66506, (785) 532-3224 Jerry Jaax, Associate Vice Provost for Research Complience 1 Fairchild Kansas State University, Manhattan KS, 66506, (785) 532-3224
SPONSOR OF PROJECT:	National Science Foundation
PURPOSE OF THE RESEARCH:	1.To investigate students' understanding of conceptions in physics, and how it depends upon the context (situation) in which it is presented 2.Develop instrument(s) that can be used by others to trace development of their students' understanding in physics over a semester (or longer).
PROCEDURES OR METHODS TO BE USED:	Interviews

ALTERNATIVE PROCEDURES OR TREATMENTS, IF ANY, THAT MIGHT BE ADVANTAGEOUS TO SUBJECT:

None

LENGTH OF STUDY:	30 - 60 min
RISKS ANTICIPATED:	No known risks
BENEFITS ANTICIPATED:	Deeper understanding of physical phenomena
CONFIDENTIALITY:	The student's performance and/or statements during interview and in survey

will not be disclosed with students' name or any identifying feature.

PARENTAL APPROVAL FOR MINORS: Not Applicable

PARTICIPATION: Voluntary

I understand this project is for research and that my participation is completely voluntary, and that if I decide to participate in this study, I may withdraw my consent at any time, and stop participating at any time without explanation, penalty, or loss of benefits, or academic standing to which I may otherwise be entitled.

I have agreed to be interviewed a total of four (4) times in Spring 2002 in connection with the study described above.

I understand that information collected from me during this interview process, including any demographic information will be kept strictly confidential by the Project Staff. Audiotapes of the interview, and their transcripts will be stored in a secure place, and will be destroyed after the publication of the research resulting from this study.

I understand that I will not be identified either by name or by any other identifying feature in any communication, written or oral, pertaining to this research.

I understand that by signing this form, I have consented to have information learned from me during the process to be used by the Project Staff in their research and any resulting publications.

I also understand that my signature below indicates that I have read this consent form and willingly agree to participate in this study under the terms described, and that my signature acknowledges that I have received a signed and dated copy of this consent form.

Participant Name: ______________________

PARTICIPANT SIGNATURE: ______________________ **Date:** ______________

Witness to Signature: ______________________ **Date:** ______________

KANSAS STATE UNIVERSITY

INFORMED CONSENT

PROJECT TITLE:	Technology & Model-Based Conceptual Assessment: Research in Students' Application of Models in Physics & Mathematics
PRINCIPAL INVESTIGATOR:	Dean Zollman 785-532-1619 (PI)
CO-INVESTIGATOR(S):	Sanjay Rebello 785-532-1539 (Co PI) Alicia R. Allbaugh 785-532-7167
CONTACT AND PHONE FOR ANY PROBLEMS/QUESTIONS:	Dean Zollman dzollman@phys.ksu.edu 785-532-1619
IRB CHAIR CONTACT/PHONE INFORMATION:	Clive Fullagar, Chair of Committee on Researh involving Human Subjects 1 Fairchild Kansas State University, Manhattan KS, 66506, (785) 532-3224 Jerry Jaax, Associate Vice Provost for Research Complience 1 Fairchild Kansas State University, Manhattan KS, 66506, (785) 532-3224
SPONSOR OF PROJECT:	National Science Foundation
PURPOSE OF THE RESEARCH:	1.To investigate students' understanding of conceptions in physics, and how it depends upon the context (situation) in which it is presented 2.Develop instrument(s) that can be used by others to trace development of their students' understanding in physics over a semester (or longer).
PROCEDURES OR METHODS TO BE USED:	Interviews

ALTERNATIVE PROCEDURES OR TREATMENTS, IF ANY, THAT MIGHT BE ADVANTAGEOUS TO SUBJECT:

None

LENGTH OF STUDY:	30 - 60 min
RISKS ANTICIPATED:	No known risks
BENEFITS ANTICIPATED:	Deeper understanding of physical phenomena
CONFIDENTIALITY:	The student's performance and/or statements during interview and in survey will not be disclosed with students' name or any identifying feature.

PARENTAL APPROVAL FOR MINORS: Not Applicable

PARTICIPATION: Voluntary

I understand this project is for research and that my participation is completely voluntary, and that if I decide to participate in this study, I may withdraw my consent at any time, and stop participating at any time without explanation, penalty, or loss of benefits, or academic standing to which I may otherwise be entitled.

I have agreed to be interviewed a total of two (2) times in Fall 2002 in connection with the study described above. I understand that I will be compensated $15 only if I attend BOTH interview sessions.

I understand that information collected from me during this interview process, including any demographic information will be kept strictly confidential by the Project Staff. Audiotapes of the interview, and their transcripts will be stored in a secure place, and will be destroyed after the publication of the research resulting from this study.

I understand that I will not be identified either by name or by any other identifying feature in any communication, written or oral, pertaining to this research.

I understand that by signing this form, I have consented to have information learned from me during the process to be used by the Project Staff in their research and any resulting publications.

I also understand that my signature below indicates that I have read this consent form and willingly agree to participate in this study under the terms described, and that my signature acknowledges that I have received a signed and dated copy of this consent form.

Participant Name: ______________________________

PARTICIPANT SIGNATURE: ______________________________ **Date:** ______________________

Witness to Signature: ______________________________ **Date:** ______________________

APPENDIX C

Example Student Responses

Interview 4, Student 2, Simple Harmonic Motion Scenario (Spring/Block):

Interviewer: Does the force vary?

Student 2: It varies.   It varies with displacement on the spring.

Interviewer: Does the velocity vary?

Student 2: It varies too.

Interviewer: Where's it maximized?

Student 2: Maximum velocity?

Interviewer: Yeah

Student 2: At the equilibrium position. The acceleration is the highest there and then it starts to slow it down as it gets farther away and then speed it back up until it gets there again and then it starts slowing it down the other direction too.

Interviewer: So acceleration?

Student 2: Yeah, the acceleration and velocity I think both will be at a max at the equilibrium position.

Interviewer: So acceleration varies as well.

Student 2: Uh huh. As the force varies the acceleration should too because the mass is constant.

Interviewer: Where's the force maximum?

Student 2: (whispered). Oh bummer.   That's at the endpoints.

Interviewer: Now we've got conflicting answers.

Student 2: I know. <huge pause> I still say the velocity is at the max in the middle. The acceleration will have to be a max at the endpoints.

Interviewer: Why is it no longer in the middle?

Student 2: Because the force is the highest at the endpoints. And the force and the acceleration are directly related…directly proportional.

Interviewer: Ok. You're still working on something there.

Student 2: I'm thinking that I've seen this before, I should have caught that. The first <> is a maximum here and the concavity is at a maximum here (midpoint).

Interview 4, Student 12, Simple Harmonic Motion Scenario (Spring/Block):

Interviewer: Does the force vary?

Student 12: Well I think…well force is equal to according to Hooke's law is dependent on the spring constant and x. Which at this point x is zero it's at equilibrium so as it moves from one way to the other, x will vary and k, is k constant? <pause> If you assume that K is constant then, x will change according to from the equilibrium therefore the force will also change.

Interviewer: Ok. Does the velocity vary?

Student 12: I would think it's constant.

Interviewer: You still are thinking.

Student 12: Uh, huh. Because you also know that Force is Mass times Acceleration and therefore if that force is varying then that makes you wonder if the acceleration is varying. Which I guess would make velocity varying. Yeah. What did I say before that, I said it was constant?

Interviewer: Yeah.

Student 12: I can't think of any equations where velocity is dependent on …well velocity is change of x over time – change of position over time. <pause> I'm going to have to say…I don't know if I agree with my first answer or not. <pause> because if velocity is constant…then that is …the acceleration is zero therefore the force would have to be nothing. …but the force is changing according to the movement in X. …what's the question again?

Interviewer: Is velocity changing?

Student 12: Yes. Ok.

Interviewer: How about the acceleration?

Student 12: If you want to find the acceleration then ma would equal –kx because of the two forces so therefore a would be –kx over m…and if you're changing x, the spring constant and the mass are the same then the acceleration will vary.

Interviewer: Tell me where it's the maximum?

Student 12: Um. I think it's going to be at the ends again. When you are at the greatest x and the greatest x in both directions.

Interviewer: Why is that?

Student 12: Well, it's getting ready to change directions and all this …if the spring constant if its…if the spring's really scrunched up it's going to shoot out farther, and as it gets really long it's going to…

Interview 5, Student 14, Electric Charges Scenarios:

One particle fixed and larger particle with like charge put in place and released.

Interviewer: What happens?

Student 14: This one will have a force pushing on it this way and this will have a force pushing on it that way and then…I assume this one is a lot stronger.

Interviewer: Stronger how.

Student 14: Like greater magnitude in charge

Interviewer: Actually it's just a larger size. The charge is still +

Student 14: Hmmmm then …<pause>…This one would be more dense if this was like supposedly <garbled> the charge would be more spread out. Otherwise….I guess the same maybe.

Interviewer: Why are they the same?

Student 14: guess it'd be different but…

Interviewer: What are you thinking? I see a debate – what's the debate going on?

Student 14: At first I was thinking of the like how you can think of things with the shell theorem. You can think of things like this is one point. Then like if you put this here and put a Gaussian surface around it soo…They don't seem to like focus on it like they seem to like …in the book or professor gray, I guess. They just like you have the forces in between them but usually they just want to know like what's the strength of the electric field or what's the strength of the force that way. Like what happens?

Interviewer: Can you tell me in this case what is going on?

Student 14: I don't know if that's right though.

Interviewer: Why not?

Student 14: Um….let's see. I guess like…if they weren't fixed and you had maybe you just set them there I guess they would you know, would be situated until they stay you know approximately like in the same spot and then if you had one fixed then the other one would just go – they'd end up like being the same distance so that they would just stay in the same spot.

Interviewer: Why would they stay in the same spot?

Student 14: Um…Now I'm over thinking this thing…I would just think of it as if you just have this here and this would have a force on it that way so there's a force on it going this way and it would move it over that way a little since this one is fixed.

Interviewer: So it moves and the first case moves. Have you changed your mind? You were rethinking everything.

Student 14: I guess they eventually slow down. If there's a force on it and nothing happens to it will keep going so maybe it will drift slower and slower away…

Interviewer: Which one?

Student 14: Both. So maybe ….I would just think they would just drift away and the force would get weaker and weaker as they get farther apart and so but if nothing was acting on it that one then it would just keep drifting away slowly I guess until something happens until something acts on it.

Interviewer: Describe its motion…

Student 14: It's going to drift

Interviewer: Speeding up slowing down…define its' drift.

Student 14: It would be slowing down….or…as like it got further away and the force wasn't as strong on it, it wouldn't have the same constant force.

Interviewer: Describe the whole picture. I put it here and let it go.

Student 14: It slows down…

Interviewer: Until it stops or…

Student 14: I guess it will stop eventually because 1/r^2 goes to zero so the force will go to zero. The force stops.

One particle fixed and identical particle with more charge put in place and released.

Interviewer: What happens?

Student 14: Same thing basically.

Interviewer: Between cases - who stops first?

Student 14: Um…whichever one wants to….going off of what I guess what I'm saying. I don't know if…I guess. If this…there's a force on this here too. … OK let's see. Normally on this one, if this wasn't fixed. And if you had something right in the middle there then like right in the exact middle then I would say these 2 forces would cancel each other out so nothing happens right there. Like if you had a point right in the middle so you'd cancel those out kind of. So I don't know if that being fixed does anything…I guess the whole time I was thinking of the force on this one but there's still like a force on this one. So…this one is on the…if the charge is stronger on this one then the force on this one would be stronger than the force on this one. I guess making it fixed throws me off. I guess I 'm just used to having like something there and something there and how does it affect something here as opposed to…. I guess you could think of moving point p here right on top there and then how does that affect it. So….because if you were right here then the force on this one wouldn't affect it there because there's no radius and this one would affect it because there is a radius. So…that would just bring me back to what I had before just thinking of the one force. That would be ok. Because of what I said before if I had it in the middle they would cancel and plus over here is stronger this one and if you're talking like a point here and I just moved to there to do what like you were talking about. So…I would say…On all three of them the force from this one is the same. And I guess what I'm saying now with my new way of thinking about it is that this doesn't matter.

Interviewer: What doesn't matter?

Student 14: This…

Interviewer: The free body doesn't matter?

Student 14: It would matter …if that was negative it would matter because it would attract in …so …unless…maybe they're just one force that's basically there…this one can add onto it. That's how that can affect it so….I do remember from like lecture where you have like three of them and you just wanted to know on this one if these were both positive the force that way…I think I'm going to stick with my going to the right due to the repulsion from that.

Interviewer: Describe how it's moving…

Student 14: Um…If the force keeps acting on it which it would it will just keep going and going…and as you're going out to infinity once you get to infinity then the limit would go to zero yeah it'd go to zero so the force will go to zero.

Interviewer: How is that going to affect the motion of this?

Student 14: The force gets weaker as it goes out so…quadrically. So…if the force is weaker weaker weaker then I guess it would slow down and stop. I'm going to say stop because the force…once there's no more force there's nothing acting on it….

Interview 5, Student 16, Electric Charges Scenarios:

One particle fixed and larger particle with like charge put in place and released.

Interviewer: What happens?

Student 16: It got bigger gosh. It's also going to be repelled from the because they're the same charge it's going to be moving along the same axis. Um…I don't know I would think that it would be the same maybe.

Interviewer: Why would it be the same?

Student 16: Um…then again no. I think it will be repelled more quickly because it will move in the opposite direction more quickly because there's a greater force between the two.

Interviewer: Why's there a greater force?

Student 16: Um because you have a bigger charge over here.

Interviewer: This is actually bigger size - it's the same charge.

Student 16: OK. I was assuming it was a bigger magnitude of charge.

Interviewer: It's a bigger ball with the same charge.

Student 16: Ok. Well in that case…I would say the same then. The same as the last one.

Interviewer: You let them go at the same time they'd go the same?

Student 16: That would be my assumption

Interviewer: So the size here doesn't matter?

Student 16: I don't think so.

One particle fixed and identical particle with more charge put in place and released.

Interviewer: What happens?

Student 16: It's going to move in the opposite on the same axis and its going to start out more quickly. It's going to be repelled. It's velocity in the opposite direction is going to be larger than the last one because it's got a greater electrostatic force between the two so…well it's going to have a actually greater acceleration is what I think because or deceleration because I think it'll slow down. It'll start out at a higher…well it will more quickly slow down. Does that make sense?

Interviewer: Uh huh. And so at the very end who has a greater velocity?

Student 16: I want to say that eventually this one will reach the same velocity as the other one but I'm not sure it will. I want to say eventually it will slow down to the same speed as the other one.

Interviewer: Why do you want to say that…do you know or is it an intuition?

Student 16: It's kind of an intuition but I know there's reasoning behind it. I think…Ok. Maybe I should change my answer here. It may be moving at a faster velocity at the end because of its charge being bigger.

Interviewer: And how did the charge make it faster at the end?

Student 16: Ok…I feel like I'm under pressure…so I'm kind of stuttering through this …I'm sorry.

Interviewer: I totally understand. You don't usually have anyone asking about your thoughts. I'm just here to hear what you think. There's no judging here.

Student 16: Ok. I know ..I'm pretty sure it's going to be slowing down more quickly than the other charge. I do think that it is going to reach the same velocity as the other charge just that it's going to reach it more quickly than the other with the same 2 charges. The only thing that's going to affect it is that it's going to decelerate more quickly than the 2 charges that are equal. Does that make sense.

One larger particle fixed and particle with identical charge put in place and released.

Interviewer: Alright. How about now?

Student 16: I think that this is going to do the same thing it's going to move in the opposite direction slowing down at the same rate.

Interviewer: If I said the mass was doubled would that change anything

Student 16: I don't think so because usually …if it's in a vacuum I don't think mass is going to matter. If its just got some …this is the only force acting on it the electrostatic force and it’s just in a vacuum where there’s no other forces on it I think it’s going to be..I don’t think that mass is going to matter. The only thing and I just thought about this , is that Ok so the force between them is the charges a constant times the charges over the radius squared and this radius is going to be a little bit larger. So maybe that would affect it a small amount. I don’t think that would have a big affect on it though because it’s going to be such a small difference anyway. But that’s the only thing.