SUPPORTING THE LEARNING OF NEWTON'S LAWS WITH GRAPHICAL DATA

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A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

Physical Science – Interdepartmental – Master of Science

2013

ABSTRACT

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Teaching physics provides the opportunity for a very unique interaction between students and instructor that is not found in chemistry or biology. Physics has a heavy emphasis on trying to alter students' misconceptions about how things work in the real word. In chemistry and microbiology this is not an issue because the topics of discussion in those classes are a new experience for the students. In the case of physics the students have everyday experience with the different concepts discussed. This causes the students to build incorrect mental models explaining how different things work. In order to correct these mental models physics teachers must first get the students to vocalize these misconceptions. Then the teacher must confront the students with an example that exposes the false nature of their model. Finally, the teacher must help the student resolve these discrepancies and form the correct model. This study attempts to resolve these discrepancies by giving the students concrete evidence via graphs of Newton's laws. The results reported here indicate that this method of eliciting the misconception, confronting the misconception, and resolving the misconception is successful with Newton's third law, but only marginally successful for first and second laws.

TABLE OF CONTENTS

LIST OF TABLES

Introduction

Physics Instruction

High school level physics offers a unique circumstance in science education. This unique circumstance has to do with students' misconceptions as they come into the course. Misconceptions are particularly unique to physics because of the topics discussed. The topics in a physics course revolve around events that students are very familiar with in everyday life. Misconceptions are the incorrect ideas students use to explain the occurrence of different phenomenon. Clement (1982) refers to these misconceptions as preconceptions and says that a source of difficulty that has been acknowledged but that has been insufficiently analyzed in the past, namely, the presence in physics of inherently difficult concepts. Difficulties with concepts appear to originate in misconceptions that the student develops on his own before entering courses (ibid). These types of phenomena are not found in a chemistry course or in the microbiology portion of a biology course, because the material discussed in those two courses are foreign to the students. They are literally starting with a blank slate and are allowed to fill it with the required material. However, the student is not a tabula rasa (blank slate) in physics. Each one comes to us having had experiences with the physical world and having organized these experiences into mental models (Redish, 1994). This notion of preconceptions is also held by Minstrell (1984) when he states that it appears that students enter with, or generate very early in instruction, alternative ideas for organizing the phenomena of the world (Minstrell, 1984). The preconceptions the previous authors refer to are defined as being the ideas the students enter into class with and although they are often misconceptions, preconceptions do not necessarily mean incorrect ideas as is the case with misconceptions. These misconceptions become the focus of physics education. The misconceptions must be brought forth, confronted, and then fixed in order to get students to truly understand physics concepts.

Misconceptions

Newton's Laws

Newton's Laws are commonly taught in physics right after a unit on motion. In the motion unit physics teachers provide students with the tools necessary to accurately describe how an object might move through space and time. After gaining these skills the next logical progression is to teach students how these different types of motion are influenced. Physics teachers are trying to get the students to answer questions such as: What is causing this object to accelerate? Why did this object slow down? How does one get an object to travel at a constant speed? Through these questions teachers are encouraging students to identify the forces that are acting on a particular object. Identifications of forces lead students to become versed in Newtonian physics. Numerous studies (Eades, 1973, Clement, 1982, Minstrell, 1984) have shown that this is a very difficult topic for students to grasp. This difficulty has been noted even at the collegiate level (Hestenes et al, 1992). The major contributor to this difficulty is the various misconceptions that students carry with them as explanations for why objects behave the way that they do.

First Law

Newton's first law says that objects in motion will stay in motion and objects at rest will remain at rest unless they are acted upon by an outside force. One misconception for first law comes from the students' lack of understanding of outside forces. There appears to be a distinction in their thinking between external forces which cause motion to change and internal forces in moving bodies which are responsible for the maintenance of that motion (Gauld, 1998). Another misconception is an observed motion is taken as evidence for a force, and the object is expected to stop moving when the force stops acting (Poon, 2006). The two misconceptions are built around students trying to explain why moving objects behave the way that they do. In the first misconception, students' are using the part of the first law that says they will remain in motion as justification for something within the object providing the impetus for the motion. They are completely negating the fact that there must be outside forces acting on any object in motion. In the second misconception the students are taking the last part of the law that says "unless acted upon by an outside force" as the reason for any object's motion. Since the outside force is the reason behind the object's motion if you remove the outside force from the object it will then come to rest. The last misconception that is commonly found with the law is based on how objects stay at rest. Minstrell (1982) found that students' believed that air and/or air pressure may be responsible for helping to keep the object where it is. In this misconception the students are trying to explain an object at rest remains at rest through the use of outside forces. This misconception comes from the idea that there must be forces acting on all sides of an object in order to keep it at rest. Based on the misconceptions one may reasonably conclude that students built these misconceptions because of a lack of understanding of what a force actually is.

Second Law

Newton's second law is typically stated as the net force on an object equals the mass of the object multiplied by the acceleration of the object. To interpret this law in any particular instance, one must determine the mass **m** and the acceleration **a** of the object of interest, and then relate these quantities to the total force $\mathbf{F_{tot}}$. This can only be done if one has first adequately described the mass of the object, its motion, and the forces due to its interactions with all other objects. Indeed, any deficiency in this description will lead to a misinterpretation of Newton's law- and thus to an incorrect solution of any problem in which this law is applied (Reif, 1995). Reif also pointed out that there are specific conditions that students must be able to accurately describe in order to interpret the law correctly. Their ability to accurately describe the conditions hinges largely on their ability to correctly define certain aspects of motion. Students often times confuse velocity with acceleration and inertia with force (Perales-Palacios and Vilchez-Gonzalez, 2002). Since the students can not differentiate between velocity and acceleration they are unable to accurately describe the forces acting on an object. This confusion leads students to the wrong interpretations of how forces influence an object's motion which is the heart of the second law. If the forces do not balance out then an object is accelerating and when the forces do balance out then the object is either at rest or moving at a constant velocity.

Third Law

Newton's third law is commonly stated as: "for every action there is an equal and opposite reaction." The most prominent misunderstanding among students is in their definition of what a force is. The most common view among students is that of force as an innate or acquired property of objects, which implies that forces are not seen as arising from an interaction between objects (Savinainen et al, 2004). Students with a concept of force as an innate or acquired property of objects would be expected to answer that the heavier, faster, etc, object would exert the greater force, while the other object would exert either a lesser force or no force at all (Brown, 1989). This means that the students treat forces as intrinsic values of the object. An example of an intrinsic value of an object would be mass. They believe that if they want to know the amount of force an object exerts that they can take that object to a something like a balance and measure it. Another issue with student's understanding of forces is that some of them believe that the object has to be in motion to exert a force. Many students do not believe that an inanimate and inert object can exert a force (Savinainen et al, 2004). Another prevalent misconception is that with two objects in contact, their mutual pushes are assumed to 'balance each other' if the two objects are not moving, but have different magnitudes (are 'unbalanced') if the objects are moving (or, for some students, accelerating) (Poon, 2006). Maloney (1984) organized these misconceptions into a couple different categories. First, mass is the only determiner for all states of motion. Greater mass exerts greater force. Second, at rest the forces are equal, but for moving systems greater mass exerts greater force. Third, at rest the forces are equal, but for moving systems the object initiating contact exerts greater forces. Fourth, for at rest and constant velocity the forces are equal, but for accelerating systems greater mass exerts greater force. Fifth, for at rest and constant velocity the forces are equal, but for accelerating systems the object initiating contact exerts greater force. These five rules do a really good job of disseminating the degree to which students are misinterpreting Newton's third law. For rules one, two, and four the students are under the misconception that forces are properties of the object. In the case of three and five the students are using the manner of the objects motion to determine the comparative magnitudes of the forces. Simply put, student's misconceptions raise from either their belief that mass is the controlling factor or that the motion of the object is responsible for the objects force.

Summary of Newton's laws Misconceptions

Although there are a number of misconceptions for each of Newton's laws there tend to be some that are more prominent then others. In the case of Newton's first law the overriding misconception is that there must be an external force acting on an object in order for it to maintain its current motion. Therefore, if you want an object to change its motion you simply remove the external force acting on the object and it will cease its current motion. For Newton's second law the most prevalent misconception is that velocity and acceleration is the same thing. This leads to a student's inability to classify the changes in motion that indicate a nonzero net force acting on the object. Likewise, this leads students into indicating that objects with a greater velocity as having greater nonzero net force acting on them as well. Lastly, the most common misconception of Newton's third law is the idea that the force exerted by one object onto another is an innate property of the object. Students often treat the force exerted by an object the same as finding the mass of an object. They fail to understand that the force exerted by one object onto another is a result of the interaction between the two objects and not an innate property of the objects.

Science Teaching

Goals of Science Instruction

The goal of science is not the accumulation of various facts, but the ability to use a small amount of basic knowledge to predict or explain many diverse phenomena. Students will have to function in a complex and rapidly changing technological world where they will profit little from knowledge that is rotely memorized or poorly understood (Reif, 1995). The difficulty is that one must be able to interpret a scientific concept unambiguously in any particular instance, a requirement not imposed on everyday concepts (ibid). Good physicists have their knowledge organized in highly coherent form which makes it easy to remember and to infer much detailed information. But students' fragmented knowledge does not provide the benefits of such a coherent structure (ibid). Kuhn and Phelps (1979) have even stated 'The most difficult obstacle confronting subjects appears to be not the acquisition of new strategies, but rather the ability to give up existing, less adequate ones'. If this is correct, then identification of students' existing strategies and conceptions becomes extremely important. What is involved here is a type of 'initial value problem' [problem designed to assess student's current conception of idea] that physics teachers must first realize exists, and then try to solve (Maloney, 1984). The students are usually asked to start an experiment by discussing with their peers and make a prediction of the outcome of that experiment. Thus students' preconceptions relevant to the phenomenon being studied are elicited. Secondly they perform the experiment and are asked to compare the outcome and prediction. If the outcome and prediction do not agree, they are asked to reflect on their observations. This challenges students' personal theories and helps them in their process of substituting their naïve belief with a more "scientific" one. If outcome and prediction do agree this strengthens beliefs who are in agreement or close to the scientifically accepted ones (Bernhard, 2000).

Designs

As with all other subjects teaching science has its own unique methods of instruction. There are a variety of different ways a teacher can approach teaching science in this case physics. Students are required to use two different modes of thought to be successful. Students need to be able to think "Convergently" (memorizing, recalling, accuracy, speed, production of orthodoxy) as well as to think "Divergently" (imagining, problem finding, linking disparate domains, surprise, variability, production of novelty) (Guilaran, 2012). Students need convergent thinking to validate their understanding of a given physical principle by successfully reapplying the principle to situations that have been given to them previously (ibid). Students will need divergent thinking to apply the principle in a situation not previously encountered because the application will be new to him at his level of experience, and he may very well need to reformulate the problem in order to solve it (ibid). High school physics is also unique among science courses at the same level because unlike chemistry or biology a lot of time is spent talking about things that are readily visible to the eye. Topics like motion, forces, and different types of energy are easily displayed in front of students. A problem that arises as a result of this macroscopic inspection is that students have already seen these actions before and have built mental models to explain them. Since they ordinarily have some predictive power in certain practical situations, they can be thought of as preconceptions that the students possess; models that can be modified in order to achieve greater precision and generality. The goal is to find teaching strategies that encourage students to articulate and become conscious of their own preconceptions by making predictions based on them. A second goal is then to encourage them to make explicit comparisons between these preconceptions, accepted scientific explanations, and convincing empirical observations (Clement, 1982). To corroborate this notion Redish says that the goal of physics teaching is to have students build the proper mental models for doing physics (Redish, 1994). Around this idea of students building correct mental models there are a couple different methods that have been proposed to solving the issue.

The first of these comes from Law et. al (1999). They propose what they call an Interactive Lecture Demonstration. To accomplish these Interactive Lecture demonstrations they use force probes and motion detectors to collect data of different events in front of the whole class and then take the following steps for success:

1. Describe the demonstration and do it for the class without Micro-computer Based Laboratory (MBL) measurements.
2. Ask students to record individual predictions.
3. Have the class engage in small group discussions with nearest neighbors.
4. Ask each student to record final prediction on handout sheet (which will be collected).
5. Elicit predictions and reasoning from students.
6. Carry out the demonstration with MBL measurements displayed.
7. Ask a few students to describe the result. Then discuss results in the context of the demonstration. Ask students to fill out "results sheet" which they keep.
8. Discuss analogous physical situations with different "surface" features. (That is, a different physical situation that is based on the same concept.)

As one can see from the instructions the teachers are getting the students to engage their misconceptions, confronting their misconceptions, and expecting in the end to be able to alter those into the correct conceptions.

The second approach by Rezaei and Katz (2002) is called the Inventive Model which incorporates both the instructivist approach as well as the constructivist approach. Generally, in instructivist approach, it is believed that students cannot be expected to construct accumulated knowledge, especially scientific knowledge, merely on the basis of hands-on activities or undirected discussions (ibid). According to constructivism, knowledge is constructed by humans and is not a set of facts, concepts, or laws waiting to be discovered. In the constructivist approach, learning emphasizes the process and not the product (ibid). Constructivism puts the emphasis on having the students build the understanding of concepts through a series of activities. These activities are designed to help the students articulate their understanding of different phenomena which leads them to an understanding of the new concept. The Inventive Model suggests that use of elements from both approaches could lead to better results if student misconceptions are deliberately and directly addressed in the lesson plans. The Inventive Model addresses these problematic realities in four phases. The model starts with a systematic analysis of student preconceptions. In the first phase many conceptual questions are asked with the aid of simulations and videotaped science experiments. In the second phase, advance organizers or other cognitive strategies, such as concept maps or analogies, are used to activate the students' prior knowledge and bridge it to the new concepts to be learned. The third phase is the heart of the Inventive Model. It includes different activities such as have students: test their preconceptions through hands on activities, compare their preconceptions with natural phenomena and related scientific theories and identify conflicts, become dissatisfied with their misconceptions through multiple problem -solving situations, and explore plausible alternatives imagined by themselves or suggested by the teacher. In the fourth phase, the teacher shows the advantages of conceptions currently accepted by the science community through multi-perspective demonstration and problem-solving practice assignments. As with the first model, the Inventive Model is built around the idea of getting students to confront their misconceptions. A difference in the Inventive Model is that students are engaged in the activity themselves instead of it being a demonstration. This notion is corroborated by Gates (2009) when he states that appropriate data collection, experimental design, and mathematical modeling are fundamental scientific skills that students should continue to practice and apply.

The third method recommended by Redish and Steinberg (1999) involves the grouping of students and the use of sophisticated equipment. Instead of watching the TAs modeling problem solving, students work in groups of three or four on carefully designed research-based worksheets. In these worksheets, students are led to make predictions and compare various lines of reasoning in order to build an understanding of basic concepts. Students work in groups of two to four with sophisticated computer equipment that permits them to obtain high quality data quickly and efficiently. They attempted to guide the students through their misconceptions without any direct input from the instructors. The students used each other and equipment to confront their misconceptions and correct them. When looking back through the three different designs it becomes apparent that they are all built on the same idea. First the students must elicit their misconception, confront the misconception, and then resolve their misconception with the appropriate physics.

Teaching Newton's Laws

With most physics content, teachers often start by expressing the content in terms of quantities defined independently of the law and subsequently defining any new quantity which the law suggests (For example we express a law as a proportionality between two quantities and use the law thus expressed to define a new quantity as equal to the constant of proportionality) (Eades, 1973). The exception to this didactic (expressing law in terms of quantities defined independently of the law and subsequently defining any new quantity which the law suggests) approach occurs in the teaching of Newton's laws when the laws and the definitions are intimately entwined so that it is all but impossible to separate and express the laws of physics which are involved. In order to address some of these issues the following Designs have been proposed by Palachios and Gonzalez (2002), Minstrell (1982), Poon (2006), and Smith and Whitmann (2007).

Designs

Since most physics teachers believe in the method of "elicit misconception, confront misconception, and then resolve misconception" as a method for instruction, there is no reason to believe that the same idea wouldn't apply to teaching Newton's laws. As before, there are multiple ways to approach teaching Newton's Laws.

One idea is to use cartoons to help students elicit their misconceptions surrounding Newton's laws. Perales-Palacios and Vilchez-Gonzalez (2002) believed in using cartoons because cartoons constituted a clear positive incentive in the students' attitude towards the subject. Students' misconceptions to a certain degree parallel the incorrect physics in the cartoons. Use of TV in the classroom to present real images and contrast the real and fictitious planes facilitates conceptual change. As stated before, they would follow the model of "elicit, confront, and resolve" the misconceptions.

The next idea by Minstrell (1982) deals with Newton's third law and ways to get students to understand force as an interaction. Most students do not realize that the force exerted by an object or on an object are the result of the interaction between the two objects. It is important to spend the time and effort to help students understand that both the active push or pull and the passive support or resistance to motion are forms of what the physicists calls force. To do this one must prepare an engaging social context, one in which students will put their thoughts about the situation up for consideration, free from fear of being chastised for being "wrong" . Secondly, several instances of an object at rest; on the solid table, on the outstretched hand, on the bendable table or spring or rubber band, must be juxtaposed. Third, arguments that explore similarity in effects and explanations across an apparent diversity of instances of objects at rest should be encouraged. Finally, students should argue for the simplest explanation that explains the most phenomena. Again, one can see how Minstrell first gets the students to elicit their misconceptions, then confront the misconceptions, and then resolve the misconception.

A second method of instruction which focuses on Newton's third law is presented by Poon (2006). To understand the Third Law, the student must appreciate the two-body interaction, not in general terms, but as the physical mechanism that determines change. It is important that the student develops a physical picture, to provide a sense of concreteness and reality, and to serve as a new platform for learning that is dissociated from the commonsense ideas such as force being a property of an object. The vagueness and the lack of predictive power of the student's commonsense ideas provide an easy way to convince the student of the inadequacy of the commonsense approach. Poon (2006) also suggests that the student be introduced to the microscopic Newtonian concept of particle-particle interaction from the start, and to develop a qualitative microscopic physical picture of the various interactions that the student comes across in the course of study. For example, instead of talking about the outcome of two objects such as a car and a truck colliding, talk about what happens when a singular particle collides with another singular particle with greater mass. The reasons for doing this are as follows: One, by going microscopic the student has a platform for learning that is dissociated from commonsense. Two, the microscopic physical picture of the interactions gives substance and meaning to macroscopic forces, and helps distinguish the various types of forces. Three, in problem solving, the student will be able to use the microscopic physical picture to sort out forces, and to use them as clues. Poon's answer to dealing with misconceptions is to attempt to avoid them if at all possible. Thus, Poon's suggestion that if you start with something they have no misconceptions about it will make it easier to bridge the gap from unknown scenario to a known scenario instead of from misconception to conception.

The last method for teaching Newton's third law comes from Smith and Whitmann (2007) and deals with instructing students through the use of tutorials. All three tutorials implemented during this study use guided-inquiry methods as a basis for teaching Newton's third law as suggested by Smith and Whitmann. The *Tutorials in Introductory Physics* (TIP) emphasizes a process of eliciting student responses, confronting incorrect answers, and resolving inconsistencies as a way of dealing with student misconceptions. The specific example for this tutorial has students drawing free-body diagrams for the external forces acting on a large mass and a small mass that come in contact with one another. The second tutorial was the *Activity-Based Tutorial* (ABT). This tutorial utilized low-friction carts and force probes to allow students to measure the different forces apparent in a collision. The last tutorial was the *Open Source Tutorials* (OST). This tutorial started with students' intuitions about a collision between a large truck and small car. The students were asked to compare the forces of the two objects and then were given computers to test different collisions. Again, in all of these tutorials the instructors are trying to elicit the students' misconceptions, confront them, and then resolve them.

Aspects of these models used in this Study

In the first method Perales-Palacios and Vilchez-Gonzalez (2002) use a visual component such as cartoons to allow the students to see the physics under discussion in action. This study will incorporate the same idea as the researcher showed the students two dynamics carts undergoing a series of different motions and interactions. This insured that all of the students were observing the same interaction for analysis.

In the second method, Minstrell (1982) emphasizes allowing students to argue their cases as a way to get the students to elicit their misconceptions. This was accomplished by this study during the generated lessons by continually asking the students to predict what they thought the outcome would be.

In the third method Poon (2006) argues that the students should be taught Newton's laws by using particle interactions. Poon (2006) believes that this will prevent the students from trying to use their misconceptions to answer the dilemmas in the first place. This study incorporates this idea by always referring to the different objects as whole entities. This means that the collisions were discussed in the manner of the collision happening to the whole cart all at the same time. The collision was not discussed in terms of what happened to one end of the cart compared to the other.

The last method by Smith and Whitmann (2007) used a number of tutorials to educate the students in Newton's laws. A tutorial is built by providing information to the student, then asking questions about the information, and then answering those questions. The lessons that were created for this study were built in exactly the same manner. The students were given data to work with, asked to predict an outcome or answer a question, and then the question was discussed by the researcher and the students.

The goal of the study reported here was to see if the students could be convinced to accept Newton's laws as actual operating explanations for changes in motion. Students usually treat Newton's laws like a cookbook recipe in which they are given a set of ingredients and they are supposed to be put together in a specific order. This notion is supported by Mazur (2003) when he stated that many students concentrate on learning 'recipes', or 'problem solving strategies' as they are called in textbooks, without bothering to be attentive to the underlying concepts. They do not treat Newton's laws as the correct way to view motion, but as someone else's way to explain motion. This often leads to learners disregarding Newton's laws as soon as the unit is over and continue on with their misconceptions. This notion can be exacerbated by the manner in which Newton's laws are often taught. They are often taught in a manner that calls upon the students to simply accept the laws as reality and often quantifiable proof is not offered. If quantifiable proof is offered it is normally done in a fashion that allows the students to question the validity of the results. So, the hypothesis of this study was that students would be more likely to accept Newton's laws as the actual operating explanation for changes in motion if the students were given unquestionable proof in the form of graphical data constructed from force probes and motion detectors.

Another goal of this study was to improve the retention of Newton's laws. Retention is accomplished through either rehearsal (repeating items over and over), elaboration (turning ideas into sentences), and summarization (explaining in own words)(Bransford et al, 2004). For the purposes of this study the desired level of retention was to fall somewhere between elaboration and summarization. It is believed by the author of this article that in between these two levels represents a shift in conception by the student. Both elaboration and summarization require the student to articulate the understanding of the concept in their own words and this ability would show that the students have altered their misconceptions to the correct conceptions. Since the study does not ask for the students thoughts during the assessment the objective was to get the students to be able to use their new understanding of Newton's laws to answer the scenarios given in the assessment correctly. This level of retention would be evident in the students score by showing a repeatable level of success or an improvement in scores. A decline in scores would indicate that the student has not altered his or her misconceptions to the correct conceptions.

The impetus behind this study was the continual dip in test scores the researcher would witness at the end of our forces unit. Students would normally score high on the motion unit that preceded the forces unit and then take a noticeable dip at the end of the forces unit. Since the two topics are so closely related the researcher was unclear as to what the cause for the weakened performance was.

The purpose of this study was to develop a series of lesson that will allow students to make the shift from their misconceptions to the acceptance of Newton's laws as the actual operating explanation for changes in motion. What makes this study different from the ones discussed earlier is that this study addresses all of Newton's laws together. In attempting to make all the laws more accessible, the laws were taught in reverse order. The reasoning behind this is that if the students can correctly identify what a force is via the third law then they will have an easier time grasping how forces influence motion via the first and second laws.

Demographics

This study was conducted during the 2012-2013 school year at DeWitt High School in DeWitt, Michigan, a suburb just north of Lansing, Michigan. As per the latest count information (2013), the High School has 954 students from grade 9 through 12. The student population is approximately 88.1% White, 5.8% Hispanic, 1.3% Asian, and 1.9% African-American.

The participating students were primarily freshman enrolled in one section of the 9^{th} grade physical science course, all of which were taught by the author. Of the 20 students that were enrolled in physical science, 9 returned the consent form (Appendix A) indicating their participation in the study. The nine students are a representative sample of the class.

Implementation

Overview

To conduct this study the order in which Newton's laws were taught were altered. In a typical physics class the laws are taught in numerical order. For this study the laws would be taught with Newton's third law first, followed by second law, and lastly first law. New lessons were also generated in order to teach Newton's laws. The first lesson developed by the researcher was to generate graphical data that supported the facts put forth by Newton's laws. Dynamics carts and Vernier probeware were used to create those graphs. The generation of these graphs will be discussed at length in the lesson portion of the article. Another difference would be the Force Concept Inventory (FCI) (Hestenes et al, 1992) tests that would be given throughout the course of the unit to track the students' progression through Newton's laws. The reason for using the FCI as an assessment is two-fold. First, Hestenes (1992) claims in his article that the test was designed as a diagnostic tool. Therefore, it can be used to determine which misconceptions are held by students. Second, Hestenes (1992) also says that the test can be used as a good measure of instructional impact by using it as a pre and post test vehicle. These two ideals were later corroborated by Huffman and Heller (1995) in their article *What does the Force Concept Inventory Actually Measure?* The order of the lessons as well as the timing for each of the Force Concept Inventory tests is listed in Table 1.

Table 1: Forces Unit Lessons and Force Concept Inventory Assessments (in chronological order)

*denotes the lessons in which the created graphical data were used

Lessons	FCI Tests
An Introduction to Forces	FCI Pre-test (given before unit is started)
Name that Force	
Newton's Third Law*	FCI Check 1 (given at the conclusion of Newton's Third Law)
Forces Cause Changes in Motion	
Newton's Second Law*	FCI Check 2 (given at the conclusion of Newton's Second Law)
Newton's First Law*	FCI Check 3 (given at the conclusion of Newton's First Law)
Exploring Newton's Laws with Interactive Physics	
Internet Lessons on Forces	FCI Post-test 1 (given at the conclusion of the unit)

During the course of the study the types of instruction included: hands-on activities, independent practice, guided practice, tutorials, and lecture. Most of the lessons (Appendices B-J) incorporated some of these aspects if not all of them. As indicated previously, the students were tested throughout the course of the unit. What is not indicated in Table 1 is that the students were tested again at the conclusion of the unit that comes after the forces unit. The desire behind this test was to see if the students had adopted Newton's laws or if they had regressed to their previous misconceptions.

Student improvement was measured using pre and posts tests (Appendix J). The pre and posts tests were a compilation multiple choice questions from a Force Concept Inventory assessment that pertained to Newton's laws and their application. The pre test was administered before the start of the unit. Posts tests were given after each of the third, second, and first law lessons. The post tests that immediately followed the lessons contained only those questions that pertained specifically to that law. The posts tests at the end of the unit had all of the third, second, and first law questions.

Lessons: Complete Lessons are located in Appendices B-J

The *Introduction to Forces* worksheet (Appendix B) introduced students to the different ways in which forces can be experienced. The room is set-up into stations that illustrate the different types of situations in which we experience forces. One station has the students look at the interactions that can take place as a result of static electricity. Another station has the students look at the interactions between magnets. The next station has students research what happens when subatomic particles interact. The fourth station has the students describe different pushes and pulls that either they exerted or were exerted on them. Lastly, the students are given the opportunity to quantify the force of gravity on different objects through the use of spring scales.

The *Name that Force* worksheet (Appendix C) was designed for students to be able to identify the different forces that are acting on an object. In this lesson students are giving a series of interactions and asked to draw Free Body Diagrams (FBD) of all the forces acting on an object. Then the students are asked to identify whether or not the object has a net force acting on the object.

The *Newton's Third Law* worksheet (Appendix D) was a direct product of the research done for this study. This lesson is designed specifically to get students to elicit their misconceptions, confront them, and then resolve them. The class was given a series of interactions and asked to predict which object hits which object harder. Then they were asked to predict what a graph of force vs. time would look like for the two objects in the interaction. After they have made their predictions they are shown the resulting force vs. time graph and asked to reconcile their prediction with the data. In order to generate the graphs two dynamics carts were collided with each other. The graphs were obtained from the force sensors that were attached to each cart. As the carts were collided the Vernier Probeware would create a force vs. time graph of the collision. In order to dispelled the myth that forces are properties of objects the mass and speed of the objects were varied.

The *Forces Cause Changes in Motion* worksheet (Appendix E) was designed to help illustrate the connection between net force and acceleration. Students were asked to pull carts across a carpeted floor with different amounts of constant force. The students experienced a cart with zero net force and then experienced two carts with different net forces.

In the *Newton's Second Law* worksheet (Appendix E) students interpreted different graphs of motion in order to determine the relationship between net force and acceleration. This lesson started with students extrapolating a velocity vs. time graph into the motion of an object. From here they were asked to describe the forces acting on the object during different sections of the graph and to identify which sections have a nonzero net force as well as the sections that display a change in velocity. After this the students were shown a force vs. time and acceleration vs. time graph of the same situation and asked to identify when the object is experiencing a force and is accelerating. In order to generate these graphs a dynamics cart was set up with a force probe and maneuvered in front of a motion detector. The graph tracks the motion of a cart starting at rest, sped up, allowed to travel at a constant speed, and then slowed down to a stop.

In *Newton's First Law* worksheet (Appendix F) the students again were called upon to elicit, confront, and resolve their misconceptions. The students were told that a cart with a block at rest on top of it will be pushed down a track and collide with an end stop. Attached to the cart and the block were accelerometers. The students were asked to predict what they think they will witness. The activity was performed and the students were shown the graph of acceleration vs. time with a line for the cart and a line for the block on the same graph. Then the students were given the scenario of a stationary cart with a block at rest on top of it suddenly starts to move. Again they were asked to explain what they think they will see and predict what they think the graph will look like. After this they were shown the graph of the motion and asked to explain why these results were obtained. The graphs were created by performing the actions outlined previously in this paragraph.

The *Newton's Laws with Interactive Physics* worksheet (Appendix G) involved letting the students manipulate the environment via a computer program to see the differing types of motion that can result of changing the forces acting on an object. The program also gave the students real time data that they can then interpret using Newton's laws.

The worksheet *Internet Lessons on Force in Physical Science* (Appendix H) for the unit was an online tutorial that walked the student through the different concepts we have discussed throughout the unit. It also provided quizzes for the students to take to test their understanding. Upon completion of those quizzes the tutorial showed the student the right answer and proceeded to explain why the answer was correct as well as why the other answers were incorrect.

The pre and posttests (Appendix J) consisted of the twenty five relevant questions from the FCI. The post test for the third law consisted of five questions (Appendix K), nine questions for the second law (Appendix L), and twelve questions for the first law (Appendix M).

Results

The first analysis of the data was done by performing T-test between the averages of the pretest (pre) and the during unit test (during), the pretest and posttest at the end of the unit (post 1), and the pretest and posttest giving after next unit of energy (post 2). Due to the small number of participants in the study it was decided that this information was not particularly useful for determining the overall effectiveness of the lessons. The results of the T-tests can be found in Appendix N.

The second form of analysis required looking at the nine subjects as a representative sample of the class and looking at different trends their scores displayed. Table 2 represents the raw data for the nine subjects that took part in the test.

Table 2: Number of Correct Answers for each Iteration of each Assessment During Study. N=9

	Third Law: (# correct out of 5)				**Second Law: (# correct out of 9)**				**First Law: (# correct out of 12)**			
Student	**Pre**	**During**	**Post 1**	**Post 2**	**Pre**	**During**	**Post 1**	**Post 2**	**Pre**	**During**	**Post 1**	**Post 2**
A	2	5	5	3	2	3	3	4	5	5	9	6
B	2	4	3	3	1	2	3	2	2	1	7	4
C	1	3	3	2	1	2	1	2	4	1	2	3
D	3	5	5	5	2	3	2	5	1	3	7	5
E	4	4	5	5	4	3	4	4	1	4	3	4
F	2	5	3	3	2	4	4	4	5	2	4	2
G	4	5	5	5	3	2	4	2	4	5	7	6
H	3	5	5	4	3	3	3	3	4	1	5	2
I	0	2	5	4	3	5	5	5	4	2	6	7
AVG	2.33	4.22	4.33	3.78	2.33	3.00	3.22	3.44	3.33	2.67	5.56	4.33

Trend Data

To get a better understanding of how well students retained the information the researcher charted out how the number of correct answers varied from one test to the next. For example, how many students increased their score, decreased their score, and stayed the same from the pre test to the during test. The number of perfect scores was also tracked for the during, post 1, and post 2 scores. Table 3 shows the number of students whose number of correct answers increased, decreased, or stayed the same, as well as how many perfect scores were recorded for the during, post 1, post 2 tests for Newton's third law.

Table 3: Third Law Trend Data. N=9

Third Law			
	Pre to During	**During to Post 1**	**Post 1 to Post 2**
Increased	8	2	0
Decreased	0	2	4
Stayed the Same	1	5	5
Perfect	5	6	3

Table 4 shows the number of students whose number of correct answers increased, decreased, or stayed the same, as well as how many perfect scores were recorded for the during, post 1, post 2 tests for Newton's second law.

Table 4: Second Law trend data. N=9

Second Law			
	Pre to During	**During to Post 1**	**Post 1 to Post 2**
Increased	6	3	3
Decreased	2	2	2
Stayed the Same	1	4	4
Perfect	0	0	0

Table 5 shows the number of students whose number of correct answers increased, decreased, or stayed the same, as well as how many perfect scores were recorded for the during, post 1, post 2 tests for Newton's first law.

Table 5: First Law trend data. N=9

First Law			
	Pre to During	**During to Post 1**	**Post 1 to Post 2**
Increased	3	8	3
Decreased	5	1	6
Stayed the Same	1	0	0
Perfect	0	0	0

Data Analysis

The primary analysis of the data was to look at the general trends for individual student scores. This analysis required looking at how many students increased their scores, decreased their scores, and stayed the same between tests. It was expected that one would see more students increasing the number of correct answers with each test or at least staying the same throughout subsequent tests if they are indeed incorporating Newton's laws into their cognitive processes while interpreting motion.

Analysis of Newton's third law assessments shows that eight students increased from *pre* to *during* tests. Since eight of the nine students increased their scores on the assessment one would conclude that the students are altering their conception of forces so that it more accurately aligns with Newton's third law. One can make the claim that their conceptions are more accurate because five of the nine students scored one hundred percent. The true test is to see if students' scores on the assessment continue to increase or at least stay the same because this will demonstrate that the students are indeed dropping their misconceptions in favor of Newton's laws. The data show five students' scores stayed the same from *during* to *post1*, two students increased from *during* to *post1*, and two students decreased from *during* to *post1,* suggesting that they have settled on a particular model to explain all scenarios. What is disappointing is to see the drop in perfect scores from *post1* to *post2*. The drop in scores indicated that most of the students were not retaining the concept of Newton's third law. According to Bransford (2004) this drop in retention signifies that the students only applied the rehearsal strategy for retention. The rehearsal strategy involves strictly memorization and no application of concepts. It is important to note that students D, E, and G continued to score perfectly on the assessment after having achieved perfection on a previous test. The continued application of the correct concept indicates that the misconception the individuals held at the beginning was reshaped into the correct conception of forces.

Analysis of Table 4 (Newton's second law) shows that six students increased their scores on the assessment from *pre* to *during* tests. Some disturbing points of analysis are that two students decreased their scores from *pre* to *during* and that none of the students received a perfect score. Ideally one is looking for students to continue to increase their scores on the assessment. It was also observed that four students stayed the same from *during* to *post1* and *post1* to *post2*. Of those four students F, H, and I held the same score from *during* to *post2.* Other interesting anomalies in the data were that students E and H never improved upon their pretest scores, and that student G's pretest score was higher then on *post2*. The lack of perfect scores for Newton's second law indicates that the lessons did not lead to a clear understanding of the concept for students. This belief by the researcher is backed up by the fact that the from the point of instruction (*during*) until *post2* the reader observes students B and G first increase their scores and then decrease their scores. The reader can also observe that students C and D decrease their scores and then increase their scores. With four of the nine participants showing no discernible upward or downward trend in scores one can reasonably conclude that the group as a whole does not have the correct concept of Newton's second law.

In the analysis of Newton's first law assessment one can see that the major increase in scores came between *during* and *post1*tests. However, this major increase is followed by a major decrease from *post1* to *post2*. Another interesting observation is a lack in the number of scores that stayed the same. There were also no perfect scores during any of the tests. This "up and down" trend suggests that this is another concept that the students did not grasp, and maybe indicative of a lot of guessing. For instance, students A, B, D, F, G, H, and I all show the same pattern of an increase in scores from *during* to *post1* followed by a decrease in scores from *post1* to *post2*.

Conclusion

Mitigating Factors

Reading Level of the Tests

One of the things that could be contributing to poor performance in the some of the students is the fact that the some may not have a reading level high enough to assimilate the questions on the test. Initially the test was administered to high school physics students (Hestenes, 1992). The assessment was given to high school freshmen in this study. If their reading skills were diminished then they would have a tough time understanding what the question was specifically asking.

Grouping

Due to a limited budget it was not possible to provide every child with an identical experience in a laboratory setting. Students worked in groups and because of this some of the students may have chosen to let other students perform the tasks in the lessons and then discuss the results afterward. Bacon (2005) calls this inaction by students “social loafing”. The problem with this is that if you are not experiencing the different forces and motions then it is difficult to connect the two concepts. For example, in *Forces Cause Changes in Motion*, if you do not actually feel the difference between pulling the cart with a zero net force and pulling a cart with a nonzero net force then it is very hard to distinguish between a zero net force and a nonzero net force when asked to do so.

Student Apathy

American schools are designed so that grades become the reinforcement for completion of a task. Often, students will ask if something is being graded. They have become conditioned throughout their schooling career to work hard for a specific grade. Therefore, their level of commitment to an assignment is often directly related to whether or not the assignment is graded.

If it is not graded then students are less likely to give their best effort on the assessment. In this study the activities as well as the assessment given were not a part of their grades. Since, they were not a part of the students' grade for the class it is plausible that the students may not have given their best effort.

Final Analysis

In conclusion, the lesson for Newton's third law with graphical data was indeed highly successful. Students were readily able to answer questions about the magnitude of two forces as a result of a collision. The data collected are a good representation of the students' ability to adjust from their misconceptions to accurate conceptions of force. By the end of the unit the students understood that the amount of force an object exerts is not in intrinsic property of the object, but a result of the interaction the object was involved.

The lessons for Newton's second law and first law were not nearly as successful as for the third law. The students struggled to interpret those graphs to begin with and consequently struggled to apply the laws in subsequent activities. The reason for the students' struggles became apparent later in the year as an interesting gap was noted in their understanding that made learning the first and second law through the interpretation of graphs almost impossible. The reason students could not apply the first two laws was because they could not conceptualize what acceleration means. High school freshmen have a difficult time understanding what is meant by the rate of change of a rate. This lack of understanding surfaced in the unit after forces when students were trying to determine if the kinetic energy of an object was increasing, decreasing, or staying the same. Students were asked to describe the motion of the object and reminded that there are four types of motion. Typical student responses were going fast, going slow, going constant, and not moving. This clearly demonstrates that they do not understand what it means to speed up or slow down. If one cannot identify when an object is undergoing acceleration how would one be able to label when it has a zero net force or a nonzero net force? This insight indicates that the variety of ways that acceleration is demonstrated to the students is not enough. As stated by Bransford (2004), students must have the background knowledge of concepts before they can master the new ones. In this case that means that students must first be able to understand acceleration before they can understand Newton's first and second laws.

Lastly, the next area of investigation would be to look into how to get students to firmly understand acceleration. Their inability to conceptualize acceleration makes learning Newton's first and second laws impossible.

APPENDICES

Appendix A: Parent Consent Form

PARENTAL CONSENT AND STUDENT ASSENT FORM

Dear Students and Parents/Guardians:

I would like to take this opportunity to welcome you back to school and invite you to participate in a research project, **Forces through Graphical Data**, which I will conduct as part of Physical Science this semester. My name is Mr. David Piggott**.** I am your science teacher this First Nine Weeks and I am also a master's degree student at Michigan State University. Researchers are required to provide a consent form like this to inform you about the study, to convey that participation is voluntary, to explain risks and benefits of participation, and to empower you to make an informed decision. You should feel free to ask the researchers any questions you may have.

What is the purpose of this research? I have been working on effective ways to teach our Forces unit, and I plan to study the results of this teaching approach on student comprehension and retention of the material. The results of this research will contribute to teachers' understandings about the best way to teach about science topics. Completion of this research project will also help me to earn my master's degree in Michigan State University's Division of Math and Science Education (DSME).

What will students do? You will participate in the instructional unit about Forces You will complete the usual assignments, laboratory experiments and activities, computer simulations, class demonstrations, and pretests/posttests just as you do for any other unit of instruction. There are no unique research activities – participation in this study will not increase or decrease the amount of work that students do. I will simply make copies of students' work for my research purposes. This project will continue from September to December 2012. I am asking for permission from both students and parents/guardians (one parent/guardian is sufficient) to use copies of student work for my research purposes. This project will continue from September to December 2012.

What are the potential benefits? My reason for doing this research is to learn more about improving the quality of science instruction. I won't know about the effectiveness of my teaching methods until I analyze my research results. If the results are positive, I can apply the same teaching methods to other science topics taught in this course, and you will benefit by better learning and remembering of course content. I will report the results in my master's thesis so that other teachers and their students can benefit from my research.

What are the potential risks? There are no foreseeable risks associated with completing course assignments, laboratory experiments and activities, computer simulations, class demonstrations, and pretests/posttests. In fact, completing course work should be very beneficial to students. Another person will store the consent forms (where you say "yes" or "no") in a locked file cabinet that will not be opened until after I have assigned the grades for this unit of instruction. That way I will not know who agrees to participate in the research until after grades are issued. In the meantime, I will save all of your written work. Later I will analyze the written work only for students who have agreed to participate in the study and whose parents/guardians have consented.

How will privacy and confidentiality be protected? Information about you will be protected to the maximum extent allowable by law. Students' names will not be reported in my master's thesis or in any other dissemination of the results of this research. Instead, the data will consist of class averages and samples of student work that do not include names. After I analyze the data to determine class averages and choose samples of student work for presentation in the thesis, I will destroy the copies of student's original assignments, tests, etc. The only people who will have access to the data are me, my thesis committee at MSU, and the Institutional Review Board at MSU. The data will be stored on password-protected computers (during the study) and in a locked file cabinet in Dr. Heidemann's locked office at MSU (after the study) for at least three years after the completion of the study.

What are your rights to participate, say no, or withdraw? Participation in this research is completely voluntary. You have the right to say "no". You may change your mind at any time and withdraw. If either the student or parent/guardian requests to withdraw, the student's information will not be used in this study. There are no penalties for saying "no" or choosing to withdraw.

Who can you contact with questions and concerns? If you have concerns or questions about this study, such as scientific issues, how to do any part of it, or to report an injury, please contact the researcher Mr. David Piggott: 13601 Panther Dr., DeWitt, MI, 48820; piggottda@dewittschools.net; 517-668-3111 and /or Dr. Merle Heidemann: 118 North Kedzie Lab , Michigan State University, East Lansing, MI 48824; heidema2@msu.edu; 517-432-2152 x 107].

If you have questions or concerns about your role and rights as a research participant, would like to obtain information or offer input, or would like to register a complaint about this study, you may contact, anonymously if you wish, the Michigan State University's Human Research Protection Program at 517-355-2180, Fax 517-432-4503, or e-mail irb@msu.edu or regular mail at 207 Olds Hall, MSU, East Lansing, MI 48824.

How should I submit this consent form? If you agree to participate in this study, please complete the attached form. Both the student and parent/guardian must sign the form. Return the form in the sealed envelope to Mr. Brian Byars in room 123 by December 1st, 2012.

Name of science course: Physical Science
Teacher: Mr. David Piggott
School: DeWitt High School

Parents/guardians should complete this following consent information:

I voluntarily agree to have ____ participate in this study.

(Print student name)

Please check all that apply:

Data:

___________ I give David Piggott permission to use data generated from my child's work in this class for her thesis project. All data from my child shall remain confidential.

___________ I do not wish to have my child's work used in this thesis project. I acknowledge that my child's work will be graded in the same manner regardless of their participation in this research.

Photography, audiotaping, or videotaping:

___________ I give David Piggott permission to use photos, audiotapes, or videotapes of my child in the class room doing work related to this thesis project. I understand that my child will not be identified.

___________ I do not wish to have my child's images used at any time during this thesis project.

Signatures:

____ _________________________

(Parent/Guardian Signature) (Date)

I voluntarily agree to participate in this thesis project.

____ __________________________

(Student Signature) (Date)

*****Important*****

Return this form in the sealed envelope to Mr. Byars in Room 123.

Appendix B: Introduction to Forces

9/21/12 Lesson 1 (Introduction to Forces)

Objectives:

-Recognize that a force is a push or a pull.

-Identify pushes and pulls that you experience.
-Describe magnetism as a repulsive force between similar poles of magnets and an attractive force between unlike poles of magnets.
-Describe static electricity as a repulsive force between similarly charged objects and an attractive force between dissimilarly charged objects.
-Draw pictures of atoms showing positively charged protons in the center (nucleus) and negatively charged electrons "orbiting" the protons.
-Explain why the atoms of one object tend to repel the atoms of another object when they get close.
-Describe gravity as an attractive force between the earth and an object on the earth.
-Determine the weight of an object in Newtons when it is on the surface of the earth.
-Recognize that forces can be felt between objects without actual contact. This is true for magnetism, electricity, and gravity.

Essential Questions:

What is the unit for Force?

How does it compare to kilograms? Pounds?

What is a force?

Anticipatory set:

Opened Lesson with asking students to determine the unit for Force using the formula F=ma. This led to the unit of kg*m/s^2 which is the same as a Newton.

Lesson:

Different stations were set up around the room that illustrated the different ways to forces can be applied.

Station 1: This station asked students to come up with three instances of something they pushed, three instances of something that pushed them, three instances of something they pulled, and three instances of something that pulled on them.

Station 2: Students observe the interaction that take place between magnets.

Station 3: Students use static electricity to move different objects.

Station 4: Students research the structure of an atom and how the particles interact with one another.

Station 5: Students hang weights and blocks of wood from spring scales and measure the effect of gravity in Newtons.

Conclusion: Class is closed with the students answering the three objectives for the day. What is the unit for Force? How does it compare to kilograms? Pounds? What is a force?

Rationale:

Station 1: This is meant to pull out the definition that a force is a push or a pull

Station 2: This shows students that forces occur without contact.

Station 3: This reinforces the idea that forces can occur without contact and that magnets are not the only source of non-contact forces.

Station 4: This gives the students the ability to understand how static friction works through the different particles within an atom.

Station 5: This station gets the students to work with forces on a quantitative level. They have to make conversions between Newtons, kilograms and pounds.

Reflection:

I found that I really have to monitor station 4. Students are ill equipped at this level to understand the subatomic particles and their relationships. I do like how this lesson introduces all of the different ways that forces can influence an object.

Name____Teacher_________________________
Period____

An Introduction to Forces

Part 1: Pushes and Pulls

1. Describe three pushes that you exerted today.
   (1)

   (2)

   (3)

2. Describe three pushes that were exerted on you today.
   (1)

   (2)

   (3)

3. Describe three pulls that you exerted today.
   (1)

   (2)

   (3)

4. Describe three pulls that were exerted on you today.
   (1)

   (2)

   (3)

Part 2: Magnetic Forces

5. Observe the hanging magnets. Which direction is north in the classroom?

6. Use a bar magnet to make the hanging magnet move. Describe your observations.

7. Do two magnets have to touch each other in order to push or pull each other?

8. Experiment with a pair of neodymium magnets.
    a. Can you get the two magnets to attract each other without actually coming in contact?
    b. Can you feel the repulsion between the two magnets as you bring similar poles closer together?
    c. Can you push hard enough to make the two magnets touch when you bring similar poles together?

Part 3: Electric Forces

9. Blow up a balloon and tie it off. Give the balloon a charge by rubbing it on your hair or on a piece of wool. Describe how the balloon interacts with the following objects.
    a. A ping pong ball on a string
    b. Tiny pieces of paper
    c. A long board balanced on a watch glass
    d. A thin stream of water
    e. Another charged balloon

10. Can you explain why the balloons acted toward each other the way they did?

All atoms are made up of charged particles called protons and electrons.

We say that a PROTON has a POSITIVE charge.
We will draw a proton as a sphere with a "+" sign. means PROTON.

We say that an ELECTRON has a NEGATIVE charge.
We will draw an electron as a sphere with a "-" sign. means ELECTRON.

It turns out that in an atom the protons (positive particles) are located in the center of the atom. The electrons can be found roaming around the rest of the atom.

11. A neutral hydrogen atom consists of one proton and one electron.
    a. Select a girl to be a proton and a boy to be an electron and act out the hydrogen atom.
    b. Draw a picture of the hydrogen atom.

c. Why do we say that this hydrogen atom is neutral?

d. How does the proton “feel” about the electron?

e. How does the electron “feel” about the proton?

12. A neutral helium atom consists of two protons and two electrons.
    a. Select girls to be protons and boys to be electrons and act out the helium atom.
    b. Draw a picture of this helium atom.

    c. Why do we say that this helium atom is neutral?

    d. How do the two electrons “feel” about each other?

    e. How do the electrons “feel” about the protons?

    f. How do the protons “feel” about the electrons?

    g. How do the protons feel about each other?

13. An atom that has only one proton is called hydrogen. An atom that has two protons is called helium. What name do we give to an atom that has three protons?

14. Let the protons be represented by girls and the electrons represented by boys.
    a. Act out an atom that has three protons.
    b. Draw a picture of the atom.

    c. Is the atom neutral? How can you tell?

15. How do two helium atoms feel about each other?
    a. Again, let girls be protons and boys be electrons. Act out two neutral helium atoms.
    b. Draw a picture of the two neutral helium atoms.

    c. How do the electrons of one helium atom "feel" about the electrons of the other helium atom?

    d. Can the helium atoms "feel" each other without actually coming in contact?

    e. Why don't the helium atoms get too close to each other?

A FORCE can be thought of as a PUSH or a PULL.

Part 4: Measuring Forces

A **Newton** is a unit of force used in the metric system.

16. Pull a spring scale with a force of one Newton.
    a. Does one Newton feel like a lot of force?
    b. Do you think that you can exert a force of 10 Newtons?
    c. Do you think that you can exert a force of 100 Newtons?
    d. Do you think that you can exert a force of 1000 Newtons?

Part 5: Gravity

17. The earth exerts a pull on all masses. How much force (in Newtons) do you think the earth exerts on the block of wood?

18. Hang the block of wood from a spring scale to find out how much it weighs.

19. Do you think that it will take more force or less force to pull the block of wood across the table than to lift it up? Give your reasoning.

20. Test out your prediction from the previous question and record your results.

21. Find out how much force (in Newtons) the earth's gravity exerts on a 1 kilogram mass.

22. Predict how much force (in Newtons) the earth's gravity exerts on a 0.5 kilogram mass.

23. Check your prediction from the previous question.

24. A one kilogram mass weighs 2.2 pounds.
    a. Estimate your weight in pounds.

    b. Calculate your mass in kilograms. Show your work.

    c. Calculate your weight in Newtons. Show your work.

Appendix C: Name that Force

9/24/12 Lesson 2 (Name that Force)

Objectives:

-Identify the forces acting on an object.

-Determine the net force acting on an object.

-Identify the forces exerted by an object.

Essential Questions:

What is Net Force?

How do you draw a Free Body Diagram?

Anticipatory set:

Start class by going over all of the answers for Introduction to Forces worksheet. Reinforce that things do not have to touch to exert a force, that opposite poles of a magnet and oppositely charged objects attract, like repel, and cover how to convert from pounds to kilograms and kilograms to Newtons.

Lesson:

First part of the lesson is to cover the first scenario with the class so they know how to report their answer. Show class how to draw a Free Body Diagram and how to determine the net force on the object. Also, must emphasize that this worksheet is only concerned with the forces acting on the person, NOT the forces the person exerts.

Next the class will go through the following scenarios and diagram the forces: standing on a chair, falling off a chair, landing on the ground, pushing off the wall while on a skateboard, two people pushing off each other while on skateboards, pushing off the wall while on their feet, and walking. In each of those scenarios they have to draw a picture of what is happening, a Free Body Diagram, and report the net force on the object.

The last part of the lesson is to have the students come back together as a class and have individuals come up to the board and draw up their answers. We then as a class go through each answer and determine its correctness.

Conclusion: Their exit slip from class that day is to explain how people swim in a pool and how people jump into the air.

Rationale:

During the activities you have to constantly get the students to focus only on the forces exert *ON* them *NOT BY* them. Later on we (as a class) are going to tie together how forces influence motion and to do that they must be able to separate the forces they exert from those exerted on them. The reason we want the students to write out the net force is because we are trying to get them to understand that forces that are exerted in opposite directions have a canceling effect on each other.

Reflection:

Students are still struggling with the separating Inertia from forces. They think that because the other persons shove created your motion that the force of the shove is still acting on you even after you are no longer touching.

Name______________________________ Team___________________________ Period____

Name That Force

1. What forces are acting on you when you stand on your chair?
   Draw a picture of yourself standing on a chair. Draw labeled arrows to show each force acting on you.
   What is the direction of the **net** force acting on you?

2. Step off your chair. What forces are acting on you while you are falling, but before you land?
   Draw a picture of yourself falling off a chair. Draw labeled arrows to show each force acting on you.
   What is the direction of the **net** force acting on you?

3. What forces are acting on you when you land?
   Draw a picture of yourself landing. Draw labeled arrows to show each force acting on you.
   What is the direction of the **net** force acting on you?

4. Put on a pair of rollerblades. Push against a wall. What forces are acting on you when you push against the wall? Draw a picture of yourself pushing the wall while wearing rollerblades. Draw labeled arrows to show each force acting on you. What is the direction of the **net** force acting on you?

5. Put on a pair of rollerblades. Push against a wall. What forces are acting on you AFTER you stop pushing the wall, but while you are still moving? Draw a picture of yourself moving AFTER you've pushed the wall while wearing rollerblades. Draw labeled arrows to show each force acting on you.
   What is the direction of the **net** force acting on you?

6. Put on a pair of rollerblades. Push against another person who is wearing rollerblades. What forces are acting on you when you push against your partner? Draw a picture of yourself pushing your partner while wearing rollerblades. Draw labeled arrows to show each force acting on you.
   What is the direction of the **net** force acting on you?

7. Put on a pair of rollerblades. Push against a partner. What forces are acting on you AFTER you stop pushing your partner, but while you are still moving? Draw a picture of yourself moving AFTER you've pushed your partner while wearing rollerblades. Draw labeled arrows to show each force acting on you.
   What is the direction of the **net** force acting on you?

8. Take your rollerblades off. Push against a wall again. Why don't you move backward this time? Draw a picture of yourself while pushing the wall without rollerblades. Draw labeled arrows to show each force acting on you.
   What is the direction of the **net** force acting on you?

9. Without rollerblades, walk across the room. Draw a picture of yourself while walking across the room without rollerblades. Draw labeled arrows to show each force acting on you. What is the direction of the **net** force acting on you?

10. When you are swimming, what force propels you forward in the pool?

11. When you jump, what force propels you upward?

12. CHALLENGE. If you were floating in space, how can you move yourself forward?

Appendix D: Newton's Third Law

9/25/12 Lesson 3 (Newton's Third Law Lesson)

Objectives:

-Given an action force exerted by one object on a second object, identify the reaction force exerted by the second object back on the first object.

Essential Questions:

What is Newton's Third Law and what does it tell us about forces?

Anticipatory set:

For the anticipatory set they are given a small piece of paper and asked to write down how they would get themselves moving if they were stranded in space and could not touch anything. Have them save the slip of paper until the end of the lesson where they will turn it in.

Lesson:

For this lesson I am going to use a series of demonstrations to illustrate Newton's Third Law. For the demonstration I am going to use two dynamics carts with force sensors placed on them. The force sensors will create a force vs. time graph of the interaction.

The first demonstration is the two carts running into each other going the same speed and composed of the same mass. The students will be asked before the demonstration which cart hits which cart harder? They will then see the demonstration and we will look at the force vs. time graph. This will allow us to determine who hit whom harder.

The second demonstration we will keep the mass the same and have one cart at rest. The students will again predict which will hit harder and they will also be asked to predict what the force vs. time graph will look like. After they have drawn their predictions on the board we will look at the force vs. time graph and see that the amount of force is identical.

The third demonstration will have the carts collide while one is traveling faster than the other. Again the students will be asked to predict which hits the hardest and to predict what the graph will look like. This procedure for predict holds true for the rest of the demonstrations.

The rest of the demonstrations were:

-Heavier cart hitting lighter cart while going the same speed.

-Heavier cart running into stationary lighter cart.

-Heavier cart running into lighter cart while traveling faster than the lighter cart.

-Lighter cart running into stationary heavy cart.

Conclusion: The class ends with four different questions. First, what is true of the Forces from A to B and B to A? What does Newton's Third Law tells us then? Given this understanding, turn to your neighbor and explain to them what a force is? Lastly, is the force for an object a property of that object?

Rationale:

The goal of the demonstrations and the accompanying data is to confront the students with their preconceived understanding of forces through momentum. Students have a tough time distinguishing an objects momentum from the force acting on an object. While they are closely related they are not one in the same. The other idea that students struggle with is the fact that forces are an interaction between two objects. Students believe that the force an object has applied to it is a property of the object that is applying the force. They believe it is a property of an object like mass is a property of an object. However, the forces acting on an object are a product of the *interaction* between the two objects. How the objects interact is the key component to determining the force, not the static properties of the objects. This is why I keep altering the properties of the interaction and showing that the forces applied to each object are perfectly identical just in opposite directions. Since the two carts are taking part in the same interaction the forces should be equal. This is also the reasoning behind the questions at the end of the lesson. I am trying to get the students to adjust their understanding from forces as a push or a pull to an interaction between objects. If they think of forces as just a push or a pull they view the force as a property of the object and not the interaction between the objects.

Reflection:

This went AMAZING! Students were unanimously putting the correct answer on the board by the end of the simulations. Students were able to tell me Newton's Third Law without any guidance what so ever. I also think that they were slowly coming around to the idea that forces are interactions and not properties.

Newton's Third Law Lesson Name_______________________

Scenario 1: Cart A running into Cart B going the same speed but in the opposite direction. Masses are equal.

Prediction:

Answer:

Scenario 2: Cart A running into a stationary Cart B and both Carts have the same mass.

Prediction:

Answer:

Scenario 3: Cart A running into Cart B traveling faster than Cart B. Masses are still equal.

Prediction:

Answer:

Scenario 4: Cart A running into Cart B going the same speed just opposite directions. Cart A has a mass two and a half times greater than B.

Prediction:

Answer:

Scenario 5: Cart A running into a stationary Cart B. Cart A has a mass two and a half times greater than B.

Prediction:

Answer:

Scenario 6: Cart A running into a Cart B going faster than Cart B. Cart A has a mass two and a half times greater than B.

Prediction:

Answer:

Scenario 7: Cart B running into a stationary Cart A. Cart A has a mass two and a half times greater than B.

Prediction:

Answer:

Summary:

What was true of the two forces (Cart A on B and Cart B on A) throughout all of these examples?

What does Newton's third law state and how do you know this to be true?

Appendix E: Forces Cause Changes in Motion and Newton's Second Law

9/26/12 Lesson 4 (Force Causes Change in Motion & Newton's Second Law Lesson)

Objectives:

- An object will change its speed and/or direction if and only if a net force is acting on it.

-Identify the forces that cause an object to change its motion (speed and/or direction).
-Use Newton's Second Law of Motion to calculate the acceleration of an object, knowing the object's mass and the forces acting on it.
-Use Newton's Second Law of Motion to calculate the net force on an object, knowing the object's mass and acceleration.

Essential Questions:

What is Newton's Second Law and how does it apply to the motion of objects?

Anticipatory set:

The students will take a Force Concept Inventory with questions pertaining to just Newton's Third Law. The next step after that is to have the students predict the type of motion they think will happen if they pull a cart with a constant 0.5N, then 1.0N, and then 1.5N on a carpeted surface.

Lesson:

The first part of the lesson was to have the students actually perform the anticipatory set scenarios in the hallway with me. When they come out there we talk about what type of motion the cart is experiencing and what forces are acting on the cart as they pull it. Once all of the groups have come out to hallway and done the experiment we go through the answers. We also draw the free body diagrams for each scenario. We then calculate the net force for each scenario. On the backside of the worksheet it gives the students a set of criteria and asks if the criteria are possible or not. Once the students finish this part of the worksheet we cover the answers as a class as well.

The next phase of the day is to go through Newton's Second Law Lesson. The students are given a velocity vs. time graph that is broken into 5 sections and asked to describe the motion of the cart on a track. 1st section is the cart standing still, 2nd is speeding up, 3rd is a constant speed, 4th is slowing down, and 5th is stopped. The next step after they have figured those sections out is to have the students draw a free body diagram for each section of the graph and then use those to determine the net force. Next we identify which sections of the graph have a net force and which sections have a change in velocity. I then ask them what we call it when the velocity of an object is changing. This should help them tie together the idea that you have a nonzero net force anytime you are accelerating. The next slide I use to show this correlation is a force vs. time graph alongside acceleration vs. time graph. They see that the peaks for both graphs occur at the same time. The last step is to pull all of this together with the equation of $F_{net} = m*a$.

Conclusion:

The last step is to pull all of this together with the equation of F_{net} = m*a. I also have the students write out what they think Newton's second laws says and what this means for an object in terms of its motion.

Rationale:

For the first activities I specifically pick those increments of pulling force to set up two different types of motion. In the case of the 0.5N pull they find that on the carpet they travel at a constant speed because friction force and the pulling force cancel each other out. They see this when we draw out the free body diagrams for each scenario. They also see that the cases where they had to accelerate they had a nonzero net force. The back side of the worksheet is designed to get them to have to come up with scenarios to break Newton's second law. They soon find that there are scenarios where there is no possible answer.

The second activity is designed to provide them with more proof. I show them different examples of graphical evidence where a change in velocity coincides with a force and where a force coincides with acceleration. We continually draw free body diagrams and calculate net forces to show that any time an object has a nonzero net force that object is accelerating.

Reflection:

The students seem to have a pretty good grasp of the idea that a nonzero net force means acceleration. Should be interesting to see how the data comes out.

Name_______________________________ Team______________________ Hour___

Forces Cause Changes in Motion

1. Obtain a spring scale and pull it with one newton of force. Does one newton seem like much force?

2. Obtain a cart and place two rectangular masses in it. Record the total mass of the cart with the two masses.

3. Attach a spring scale to the cart's string. Be sure that the spring scale is zeroed.
   a. Predict what the cart's motion will be like if you were to pull it with a constant force of 0.5 Newton.

   b. Pull the cart across the floor with a constant force of 0.5 Newton. Describe the motion of the cart.

   c. Predict what the cart's motion will be like if you were to pull it with a constant force of 1.0 newton instead of 0.5 Newton.

   d. Pull the cart across the floor with a constant force of 1.0 newton. Compare the motion of the cart to its motion when it was pulled by 0.5 Newton.

   e. Predict what the cart's motion will be like if you were to pull it with a constant force of 1.5 Newtons.

   f. Pull the cart across the floor with a constant force of 1.5 Newton. Compare the motion of the cart to its motion when it was pulled by 0.5 Newton.

4. True or False. “If you pull a cart with a constant force, then it will go at a constant speed.”

5. True or False. “The greater the force acting on an object, the faster the object’s motion is changed.”

The NET FORCE acting on an object is the sum of all the force acting on it. The net force on an object is zero if the forces acting on it tend to cancel each other out. For instance, as you sit in your chair, the earth’s gravity is pulling you down, but the chair is pushing you up with an equal amount of force. This makes the net force on you zero.

6. Give an example of an object which is speeding up and has a net force acting on it.

7. Give an example of an object which is speeding up, but has no net force acting on it.

8. Give an example of an object which is slowing down and has a net force acting on it.

9. Give an example of an object which is slowing down, but has no net force acting on it.

10. Give an example of an object which is changing its direction and has a net force acting on it.

11. Give an example of an object which is changing its direction, but has no net force acting on it.

12. Give an example of an object which is at rest and has a net force acting on it.

13. Give an example of an object which is at rest and has no net force acting on it.

14. True or False. “If an object is going at a constant speed and in a constant direction, then the forces acting on it cancel each other out.”

15. True or False. “If an object’s speed and/or direction are changing, then the forces acting on it do not cancel each other out.”

Newton's Second Law Name_________________________

1. Starting with this velocity vs. time graph, describe the motion of the object for each section and explain how you know its motion.

Section A:

Section B:

Section C:

Section D:

Section E:

2. Based on what you know about the objects motion in the different sections, draw the Free-Body Diagram for the cart during each of the sections. Make sure you include the Net Force as well.

Section A:

Section B:

Section C:

Section D:

Section E:

3. In which sections of the motion is there a net force present?

4. In which sections of the motion is the velocity changing?

5. What do we call it when we say that the velocity is changing?

6. Now look at sections B and D on the force vs. time and acceleration vs. time graphs. What do you notice about the two graphs?

7. How would you say that Net Force and Acceleration are related than?

8. So what type of motion is an object experiencing if there is a net force other than zero present?

9. CHALLENGE! Give the two different sets of graphs; can you explain what it is happening, in terms of motion, which would cause them to look different?

Case 1

Case 2

Appendix F: Newton's First Law

9/27/12 Lesson 5 (Newton's First Law)

Objectives:

Demonstrate an understanding of Newton's First Law of Motion. "An object tends to maintain its speed and direction when there is no net force acting on it."

Essential Questions:

What is Newton's First Law and how does it apply to the motion of objects?

Anticipatory set:

The students will take a Force Concept Inventory with questions pertaining to just Newton's Second Law. This takes a significant portion of class time.

Lesson:

The first motion they are given is a cart traveling at a constant speed and runs into the end stop of the track and a block is riding along on top of the cart. The students then have to predict what they will observe when this motion is carried out. The students then observe the motion and record what they observed. The next step is to look at the acceleration vs. time graph of the observed motion and determine what the peaks mean. After we have determined that the peaks represent acceleration of the two objects I will ask them what acceleration of an object also implies. The next thing I ask them to analyze is where the peaks occur with respect to each other. They see that the peak for the cart occurs before the peak for the block. Next I ask them to explain why the block does not accelerate at the same time as the cart and vice versa? The next motion the students are asked to analyze is the block and cart sitting at rest and suddenly the cart moves. The students again are asked to predict the outcome. The students are also asked to predict what they think the graph will look like? Then the students are shown the outcome and asked to explain the outcome based on Newton's first law?

Conclusion:

The class is ended with the students turning to each other and explaining how Newton's First Law influences motion. We then go through their answers as a class.

Rationale:

I am trying to get the students to see that the two objects do not accelerate at the same time with the graphs. Once they understand that the two objects do not accelerate at the same time we can then discuss what forces are present at the different times. After they understand that we talk about what happens in terms of the motion of the objects before and after the forces. This should get them to see that objects keep their motion until an outside force acts upon them.

Reflection:

The students seemed to struggle with when things are considered a part of the same system. At first they thought that the block and the cart were attached because they were in contact with each other. Once they understood that they were not attached it then made sense to them that they will not experience the same forces.

Newton's First Law Name____________________

Motion #1: Cart with a block riding on top of it is traveling along the track when the cart runs into the end stop.

Predict what you think you will see when the motion is performed:

Now write down what you observed of the motion:

Looking at the first graph that has acceleration vs. time what do the two spikes at the far right mean?

What do the two peaks representing acceleration also imply?

What do you notice about the acceleration of the block compared to the cart during the first peak on the acceleration vs. time graph?

What do you notice about the acceleration of the cart compared to the block during the second peak on the acceleration vs. time graph?

Why does the block not accelerate with the cart during the first peak?

Why does the cart not accelerate with the block during the second peak?

Knowing that the block is on top of the cart during this motion how does this data support Newton's First Law?

Motion #2: A cart with a block on top of it is sitting at rest. Suddenly the cart starts to move.

First, Predict what you think will happen with the block.

Second, Predict what the graph of acceleration vs. time would like for this scenario.

Now that you have seen the graph of this motion, describe how this data supports Newton's First Law.

Appendix G: Exploring Newton's Laws on Interactive Physics

9/28/12 Lesson 6 (Exploring Newton's Laws on Interactive Physics)

Objectives:

-Use Newton's Second Law of Motion to calculate the acceleration of an object, knowing the object's mass and the forces acting on it.

-Use Newton's Second Law of Motion to calculate the net force on an object, knowing the object's mass and acceleration.

-Given an action force exerted by one object on a second object, identify the reaction force exerted by the second object back on the first object.

Essential Questions:

I can explain how an object changes its motion.

I can calculate the net force on an object.

I can build a simulation on Interactive physics to demonstrate a given motion of an object.

Anticipatory set:

The anticipatory set for this lesson are the first two problems of the worksheet. They work as an introduction to the program. The students are instructed to raise their hand if they get stuck on the first part as it is critical for success in latter portions of the worksheet. The first question introduces the students to the commands of the program and the second question demonstrates how to measure different quantities of an object.

Lesson:

Problem number three has the students observe the motion of an object that has a constant nonzero net force. Questions four, five, and six have the students build two simulations that reinforce Newton's second law. One to demonstrate that the more force applied to an object the faster it will change its motion. The second demonstration has the students demonstrate that it is not easier to speed up a more massive object than a lighter one. In question seven the students take measurements of a block of wood, input their measurements into the program, and then run the program to test the outcome. In question eight the students gather more measurements, input the measurements, and run the program. The difference between seven and eight is that the object is at rest in seven and in motion in eight. This procedure holds true for questions nine and ten as well. In nine the students are confronted with the idea that static friction must be overcome for an object to start to move. In question ten students observe what happens when an object in motion has a force applied to it in the opposite direction of its motion.

Conclusion:

Class is concluded by going through the true/false questions in number eleven.

Rationale:

This program does a great job of drawing out students misconceptions. It will carry out a motion perfectly based on the parameters that are input into it. So when students see the objects doing something other than what they observed in real life they have to go back and figure out why it is performing that way on the computer. This lesson does a great job of force students to use free body diagrams for different types of situations.

Reflection:

Since this is the first time they see the computer program things go a little rough. Once they get used to it things go a lot quicker. The conclusion part is essential in this exercise because they needed to be reminded what it is I wanted them to learn. The objectives have a tendency to get lost in their attempts to learn the computer program.

Name______________________________ Team__________________________ Period____

Exploring Newton's Laws of Motion with Interactive Physics

It is reasonable to believe that objects in motion naturally come to rest. This is consistent with our everyday experiences. For instance, if you push a book across the table, it will slow down until it stops. Even if you are pushed while wearing rollerblades, you will eventually come to a stop.

Galileo argued that in the absence of a force, an object will tend to keep on going. The reason that the pushed book comes to a stop is because of the friction force slowing it down. The same is true for the person wearing rollerblades.

Sir Isaac Newton formalized this idea in his First Law of Motion, sometimes referred to as the Law of Inertia.
The First Law is most popularly stated, "An object at rest stays at rest and an object in motion stays in motion unless acted upon by an unbalanced force."

However, the First Law is more accurately stated,
"An object's speed and direction remain constant unless there is an external net force acting on it."

The First Law of Motion was undiscovered for most of human history because we do not live in an environment which is free of friction's retarding force. Let's imagine ourselves in a frictionless and gravity-free environment. To experiment in such a hypothetical world, we will use computer simulations.

1. Open up the Interactive Physics file called Newton1.ip. It is located on the shared drive under Teachers/HS/Physical Science/Unit 2 - Forces/Newton1.ip. You will observe a picture of a block of wood floating in space.
   a. How long is the block of wood?

   b. How wide is the block of wood?

   c. What is the mass of the block of wood? Hint: Click on the block and open the Properties option under the Window menu.

   d. Select Run. Why doesn't the block move?

   e. "An object at rest ____."

2. This time you will observe a block of wood that is already in motion. Open the simulation named
Newton2.ip.

a. Run the simulation. Notice the "clock" on the screen. Use the clock and the grid to measure the speed of the block of wood. Record your results, here.

b. Did the block move at a constant speed? How can you tell?

c. Why didn't the block slow down?

d. "An object in motion ____."

3. This time we will have the block of wood being pushed by a force.

a. Open up Newton3.ip and run the simulation. What happens to the speed of the block? Why?

b. How much force was being exerted on the block? Hint: Click on the force arrow and open the Properties option from the Window menu.

c. Predict what will happen to the block of wood if you reduce the size of the force by a factor of ten.

d. Check your prediction from part (c). Did the block of wood still accelerate? Give the data to support your response.

e. What is the direction of the net force acting on the block of wood?

f. Will the block of wood still accelerate if you give it only 0.001 Newton of force?

g. Check your answer to part (f). Give data to support your response.

4. Newton's Second Law of Motion describes the relationship between the amount of force exerted on an object and how fast its motion changes. Which of these statements make sense to you? Circle the ones that you think are true and cross off the ones that you think are false.

a. “The more force you apply to an object the faster it will change its motion.”

b. “A more massive object is easier to speed up than a less massive one.”

c. “The faster an object is going the harder it is to stop it.”

5. Design a computer simulation to test your answer to #4(a) in a frictionless and gravity-free environment.
Show your results to the teacher.

6. Design a computer simulation to test your answer to #4(b) in a frictionless and gravity-free environment.
Show your results to the teacher.

Name______________________________ Team___________________________ Period____

Exploring Newton’s Laws of Motion with Interactive Physics

Meanwhile, back on Earth . . .

7. Obtain a spring scale and a block of wood with a hook on one end.
   a. How much does the block weigh in Newtons?

   b. Knowing that a 1 kg mass weighs 9.8 Newtons on the surface of the earth, calculate the mass of your block of wood by setting up and solving a proportion.

   c. Place the block of wood on the table and draw a free body diagram of it showing all the forces acting on the block with labeled arrows. Each arrow should include the magnitude of the force.

d. Calculate the net force acting on the block.

e. Open the Interactive Physics file Newton7.ip and modify the mass of the block to match your own.
   Run the simulation. What happens to the position of the center of the block?

f. Why doesn't the block move?

g. What forces are acting on the block?

h. What is the magnitude of the net force acting on the block?

i. What is the direction of the net force acting on the block?

8. Get your block of wood going 1.0 meter/second across the table and let it go.
   a. What happens to the block of wood after you let go of it? Why?

   b. Draw a free body diagram of it after you have let go of it. Check your answer with the teacher.

   c. How far did your block travel before it stopped?

   d. Modify your Newton7.ip simulation to match what happens to the block after you let go of it.

To do that, first give the block an initial speed of 1.0 meters/second. Run the simulation and show it to your teacher.

e. How far did the block travel in your simulation? Does this match your answer to part (c)?

f. Modify the block's coefficient of friction until the distance traveled in the simulation matches your actual experiment. What value did you use for the coefficient of friction?

g. Using your simulation as a guide, go back and quantify your free body diagram in part (b).

h. What is the magnitude of the net force acting on the block after you let go of it?

i. What is the direction of the net force acting on the block after you let go of it?

j. How will the size of the speed of the block when you let go of it affect the results?

k. Test your prediction from part (j) with the simulation. Report your results.

l. What is the "stopping distance" for the block of wood when the initial speed is 1.0 meter/second?

m. What is the "stopping distance" for the block when the initial speed is 2.0 meters/second?

n. What is the "stopping distance" for the block when the initial speed is 3.0 meters/second?

o. TRUE or FALSE. When the initial speed is doubled, the stopping distance is doubled.
p. TRUE or FALSE. When the initial speed is tripled, the stopping distance is tripled.
q. TRUE or FALSE. The stopping distance for a car going 70 mph is twice as far as the stopping distance for a car going 35 mph.
r. TRUE or FALSE. The stopping distance for a car going 75 mph is three times as far as the stopping distance for a car going 25 mph.

Name______________________________ Team___________________________ Period____

Exploring Newton's Laws of Motion with Interactive Physics

Still on Earth . . .

9. This time we will pull the block with 0.50 Newton of force, like in Problem #3.

a. With your block of wood resting on the table, pull it with a force of 0.5 Newtons using a spring scale. Did the block move? Explain.

b. Open the Interactive Physics file Newton9.ip and modify the mass of the block to match your block and modify the coefficient of friction to match the value you found in Problem #8. Run the simulation. Why didn't the block move?

c. Draw a free body diagram of the block while you are pulling it. Check your answer with the teacher after you make sure that you have a labeled arrow for each force acting on the block and a magnitude for each force.

d. What is the magnitude of the net force acting on the block?

e. What is the direction of the net force acting on the block?

f. Why did an object at rest stay at rest this time?

g. Now pull the block with a force of 2.0 Newtons. What happens this time? Why?

h. Modify your simulation so that the pull on the block is 2.0 Newtons. Why does the block speed up this time?

i. How fast does the block speed up? That is, by how much does the speed of the block increase each second? Explain how you got your answer.

j. What do we call the quantity that you calculated in part (i)?

k. Draw a free body diagram of the block while you are pulling it with a force of 2.0 Newtons. Check your answer with the teacher after you make sure that you have a labeled arrow for each force acting on the block and a magnitude for each force.

l. What is the magnitude of the net force acting on the block?

m. What is the direction of the net force acting on the block?

n. According to Sir Isaac Newton's Second Law of Motion,
Use it to predict the block's acceleration.

o. Does your answer to part (n) match your answer to part (i)?

10. Open up simulation Newton10.ip to discover what happens when the block already has initial speed, but there is someone pushing against it. Describe what things you learned by playing with Newton10.ip.

11. TRUE or FALSE.

_____________ a. An object in motion always stays in motion.

_____________ b. If an object is going at constant speed, then there must be a net force acting on it.

_____________ c. A net force can cause an object to slow down.

_____________ d. The direction of the net force acting on an object is always the same as the direction that the object is moving.

_____________ e. If an object is speeding up, then there must be a net force acting on it.

_____________ f. An object at rest always stays at rest.

_____________ g. If there is no net force acting on an object, then it will slow down.

Appendix H: Internet Lessons

10/1/12 Lesson 7 (Internet Lessons on Newton's Laws)

Objective:

-Understand Newton's Laws and be able to use them to explain changes in motion.

Essential Questions:

What is Newton's 1^{st} Law? 2^{nd}? 3^{rd}?

How do Newton's Laws explain changes in motion?

Anticipatory set:

Start class with the series of true/false questions from number eleven in the Interactive Physics packet.

Lesson:

This lesson is review of Newton's Laws. Students go through and online tutorial provided by thephysicsclassroom.com. The tutorial explains Newton's Laws as well as gives sample problems for the students to work through. The sample problems explain why the correct answer is the correct answer as well as explain why the incorrect answers are incorrect.

Conclusion:

Class is concluded by going through the essential questions on the board.

Rationale:

This lesson allows the students to be exposed to Newton's Laws through a voice that is not mine. The sample problems are highly beneficial for the students as it creates a safe environment for them to be incorrect.

Reflection:

Great review!

Name________________________________ Partner________________________ Period___

Internet Lessons on Force for Physical Science

Go to the website http://www.physicsclassroom.com
Then go to Physics Tutorial.
From the menu, select "Newton's Laws"
Complete the following webpages.
Lesson 1: Newton's First Law of Motion
"Newton's First Law"
Notes:

"Inertia and Mass"
Notes:

Check Your Understanding

1.

2.

3.

4.

5.

6.

7.

"State of Motion"

Notes:

Check Your Understanding

1.

2.

"Balanced and Unbalanced Forces"

Notes:

Check Your Understanding

1.

2.

3.

4.

Name______________________________ Partner_______________________ Period___

Internet Lessons on Force for Physical Science

Go to the website http://www.physicsclassroom.com
Then go to Physics Tutorial.
From the menu, select "Newton's Laws." Complete the following webpages.
Lesson 2: Force and Its Representations

"The Meaning of Force"

Notes:

"Types of Forces"

Notes:

Check Your Understanding

1.

2.

3.

"Drawing Free-Body Diagrams"

Notes:

"Determining the Net Force"

Notes:

Check Your Understanding

1.

2.

Name______________________________ Partner_______________________ Period___

Internet Lessons on Force for Physical Science

Go to the website http://www.physicsclassroom.com
Then go to Physics Tutorial.
From the menu, select "Newton's Laws." Complete the following webpages.
Lesson 3: Newton's Second Law of Motion

"Newton's Second Law"

Notes:

Check Your Understanding

1.

2.

3.

4.

"The Big Misconception"

Notes:

"Finding Acceleration"

Notes:

Practice:

1.

2.

3.

Checking Your Understanding

1.

2.

"Finding Individual Forces"

Notes:

Practice:

1.

2.

3.

4.

5.

Checking Your Understanding

1.

2.

"Free Fall and Air Resistance"

Notes:

Name________________________________ Partner________________________ Period___

Internet Lessons on Force for Physical Science

Go to the website http://www.glenbrook.k12.il.us/gbssci/phys/Class/BBoard.html
From the menu, select "Newton's Laws." Complete the following webpages.
Lesson 4: Newton's Third Law of Motion

"Newton's Third Law"

Notes:

Check Your Understanding

1.

2.

3.

4.

"Identifying Action and Reaction Force Pairs"

Notes:

Check Your Understanding

1.

2.

Appendix I: Review

10/2/12 Lesson 8 (Review Day)

Objective:

-Understand Newton's Laws and be able to use them to explain changes in motion.

Essential Questions:

What is Newton's 1st Law? 2nd? 3rd?

How do Newton's Laws explain changes in motion?

Anticipatory set:

Start class with a sample problem that causes the students to use one of Newton's Laws to solve it.

Lesson:

Students are given a 'sample test' to complete during class. I treat this just like a test situation where they are not allowed to work with partners. They take it like the actual test.

Conclusion:

At the end of class I go through the answers with the students so they have the correct material to study.

Rationale:

By having them take a sample test it shows each individual student where they are not proficient. Time is also allotted at the end for students to see it done correctly and to ask any questions they need answered.

Name______________________________ Date___________________________ Period____

Sample Physical Science Test on Forces

1. Place Cart A at rest on a track.
   a. The cart's mass is 0.5 kilograms. With how much force is the earth's gravity pulling down on it? Answer in Newtons.

   b. Explain why the cart does not accelerate downward even though the earth's gravity is pulling down on it.

   c. Draw a free body diagram for it, describing each force acting on the cart with a **labeled** arrow.

   d. Are the forces acting on Cart A balanced or unbalanced? How can you tell?

   e. What is the direction of the net force acting on Cart A? How can you tell?

2. Place Cart A on the left end of the track and give it a gentle push so that it moves slowly to the right. Answer these questions about the motion of Cart A **after** you let go of it, but while it is moving.
   a. Draw a free body diagram for Cart A, describing each force acting on the cart with a **labeled** arrow.

b. Are the forces balanced or unbalanced? How can you tell?

c. What is the direction of the net force acting on Cart A? How can you tell?

3. Orient Carts A and B so that they magnetically repel when they are close to each other. Maintaining the same orientation, move Cart A to the left end of the track and Cart B to the center of the track. Give Cart A a gentle push and watch it collide with Cart B.

a. Does Cart A exert a force on Cart B, even though they do not touch each other? How can you tell?

b. Does Cart B exert a force on Cart A, even though they do not touch each other? How can you tell?

4. During the collision in problem #3,

a. Describe the forces acting on Cart B with a free body diagram.

b. Are the forces acting on Cart B during the collision balanced or unbalanced? How can you tell?

c. What is the direction of the net force acting on Cart B? How can you tell?

5. During the collision in problem #3,

a. Describe the forces acting on Cart A with a free body diagram.

b. Are the forces acting on Cart A during the collision balanced or unbalanced? How can you tell?

c. What is the direction of the net force acting on Cart A? How can you tell?

6. How would the results of the collision in problem #3 be different if you pushed Cart A with less force? Give your reasoning.

7. How would the results of the collision in problem #3 be different if you pushed Cart A with more force? Give your reasoning.

8. Observe the teacher demonstrate the ball popping out of a chimney cart and landing back in it. Predict what will happen if the cart is moving when the ball is released. Where will the ball land relative to the cart? Give your reasoning.

9. Draw a picture of the earth orbiting the sun. Draw a labeled arrow for each significant force acting on the earth.

10. Imagine that the suns gravitational pull on the earth were to suddenly disappear. What path would the earth follow? Draw a picture to describe your answer.

11. You are a police officer checking to see if cars are speeding on Clark Road. Your radar gun is not working, but you figure that you can easily calculate their speeds anyways. The speed limit is 20 meters/sec (45 mph). With your odometer, you measure off a distance of 0.1 mile (160 meters). Using your watch, you measure the time it takes for cars to cover the marked distance.
    a. The first car that goes by is a 1500 kg sedan heading east. It seems to be going at a constant speed. You find that it takes 9.2 seconds to cover the marked distance.
        i. Was the car speeding? Justify your response.

        ii. What was the acceleration of the car?

        iii. What was the magnitude of the net force acting on the car?

iv. What was the direction of the net force acting on the car?

b. The next vehicle to pass you is a 3000 kg truck heading west, also at a constant speed. You measure the time it takes to cover the marked distance to be 8 seconds.
i. How did the velocity of the truck compare to the velocity of the car? Justify your response.

ii. How did the pull of gravity on the truck compare to the pull of gravity on the car? Justify your response.

iii. How did the magnitude of the net force acting on the truck compare to the magnitude of the net force acting on the car?

iv. How did the direction of the net force acting on the truck compare to the direction of the net force acting on the car?

Appendix J: Pre/Post Test

Force Concept Inventory

1. Two metal balls are the same size but one weighs twice as much as the other. The balls are dropped from the roof of a single story building at the same instant of time. The time it takes the balls to reach the ground below will be:

    a. About half as long for the heavier ball as for the lighter one
    b. About half as long for the lighter ball as for the heavier one
    c. About the same for both balls
    d. Considerably less for the heavier ball, but not necessarily half as long
    e. Considerably less for the lighter ball, but not necessarily half as long

2. The two metal balls of the previous problem roll off a horizontal table with the same speed. In this situation:
    a. Both balls hit the floor at approximately the same horizontal distance from the base of the table
    b. The heavier ball hits the floor at about half the horizontal distance from the base of the table than does the lighter ball
    c. The lighter ball hits the floor at about half the horizontal distance from the base of the table than does the heavier ball
    d. The heavier ball hits the floor considerably closer to the base of the table than the lighter ball, but not necessarily at half the horizontal distance
    e. The lighter ball hits the floor considerably closer to the base of the table than the heavier ball, but not necessarily at half the horizontal distance

3. A stone dropped from the roof of a single story building to the surface of the earth:
    a. Reaches a maximum speed quite soon after release and then falls at a constant speed thereafter
    b. Speeds up as it falls because the gravitational attraction gets considerably stronger as the stone gets closer to the earth
    c. Speeds up because of an almost constant force of gravity acting upon it
    d. Falls because of the natural tendency of all objects to rest on the surface on the earth
    e. Falls because of the combined effects of the force of gravity pushing it downward and the force of the air pushing it downward

4. A large truck collides head-on with a small compact car. During the collision:
    a. The truck exerts a greater amount of force on the car than the car exerts on the truck
    b. The car exerts a greater amount of force on the truck than the truck exerts on the car
    c. Neither exerts a force on the other, the car gets smashed simply because it gets in the way of the truck
    d. The truck exerts a force on the car but the car does not exert a force on the truck
    e. The truck exerts the same amount of force on the car as the car exerts on the truck

USE THE STATEMENT AND FIGURE BELOW TO ANSWER THE NEXT TWO QUESTIONS (5 AND 6).

The accompanying figure shows a frictionless channel in the shape of a segment of a circle with center at "O". The channel has been anchored to a frictionless horizontal tabletop. You are looking down at the table. Forces exerted by the air are negligible. A ball is shot at high speed in the channel at "p" and exits at "r".

5. Consider the following distinct forces:
    1. A downward force of gravity
    2. A force exerted by the channel pointing from q to O
    3. A force in the direction of motion
    4. A force pointing from O to q

   Which of the above forces is (are) acting on the ball when it is within the frictionless channel at position "q"?

    a. 1 only
    b. 1 and 2
    c. 1 and 3
    d. 1, 2, and 3
    e. 1, 3, and 4

6. Which path in the figure below would the ball most closely follow after it exits the channel at "r" and moves across the frictionless tabletop?

7. A steel ball is attached to a string and is swung in a circular path in a horizontal plane as illustrated in the accompanying figure below. At the point P indicated in the figure, the string suddenly breaks near the ball. If these events are observed from directly above as in the figure, which path would the ball most closely follow after the string breaks?

USE THE STATEMENT AND FIGURE BELOW TO ANSWER THE NEXT FOUR QUESTIONS (8 through 10).

The figure depicts a hockey puck sliding with constant speed V_o in a straight line from point "a" to point "b" on a frictionless horizontal surface. Forces exerted by the air are negligible. You are looking down on the puck. When the puck reaches point "b," it receives a swift horizontal kick in the direction of the heavy print arrow. Had the puck been at rest at point "b," then the kick would have set the puck in horizontal motion with speed V_k in the direction of the kick.

8. Which of the paths below would the puck most closely follow after receiving the kick?

9. Along the frictionless path you have chosen in questions 8, the speed of the puck after receiving the kick:
    a. Is constant
    b. Continuously increases
    c. Continuously decreases
    d. Increases for a while and decreases thereafter
    e. Is constant for a while and decreases thereafter

10. Along the frictionless path you have chosen in question 8 , the main force(s) acting on the puck after receiving the kick is (are):
    a. A downward force of gravity
    b. A downward force of gravity, and a horizontal force in the direction of motion
    c. A downward force of gravity, an upward force exerted by the surface, and a horizontal force in the direction of motion
    d. A downward force of gravity and an upward force exerted by the surface
    e. None. (No forces act on the puck)

11. A ball is fired by a cannon from the top of a cliff as shown in the figure below. Which of the paths would the cannon ball most closely follow?

12. A boy throws a steel ball straight up. Consider the motion of the ball only after it has left the boy's hand but before it touches the ground, and assume that forces exerted by the air are negligible. For these conditions, the force(s) acting on the ball is (are):
    a. A downward force of gravity along with a steadily decreasing upward force
    b. A steadily decreasing upward force from the moment it leaves the boy's hand until it reaches its highest point; on the way down there is a steadily increasing downward force of gravity as the object gets closer to the earth
    c. An almost constant downward force of gravity along with an upward force that steadily decreases until the ball reaches its highest point; on the way down there is only a constant downward force of gravity
    d. An almost constant downward force of gravity only
    e. None of the above. The ball falls back to the ground because of its natural tendency to rest on the surface of the earth

13. A bowling ball accidentally falls out of the cargo bay of an airliner as if flies along in a horizontal direction. As observed by a person standing on the ground and viewing the plane as in the figure below, which path would the bowling ball most closely follow after leaving the airplane?

USE THE STATEMENT AND FIGURE BELOW TO ANSWER THE NEXT TWO QUESTIONS (14 and 15).

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

14. While the car, still pushing the truck, is speeding up to get up to cruising speed:
    a. The amount of force with which the car pushes on the truck is equal to that with which the truck pushes back on the car
    b. The amount of force with which the car pushes on the truck is smaller than that with which the truck pushes back on the car
    c. The amount of force with which the car pushes the truck is greater than that with which the truck pushes back on the car
    d. The car's engine is running so the car pushes against the truck, but the truck's engine is not running so the truck cannot push back against the car. The truck is pushed forward simply because it is in the way of the car
    e. Neither the car nor the truck exerts any force on the other. The truck is pushed forward simply because it is in the way of the car

15. After the car reaches the constant cruising speed at which its driver wishes to push the truck:
    a. The amount of force with which the car pushes on the truck is equal to that with which the truck pushes back on the car
    b. The amount of force with which the car pushes on the truck is smaller than that with which the truck pushes on the car
    c. The amount of force with which the car pushes the truck is greater than that with which the truck pushes back on the car
    d. The car's engine is running so the car pushes against the truck, but the truck's engine is not running so the truck cannot push back against the car. The truck is pushed forward simply because it is in the way of the car
    e. Neither the car nor the truck exerts any force on the other. The truck is pushed forward simply because it is in the way of the car

16. An elevator is being lifted up an elevator shaft at a constant speed by a steel cable as shown in the figure below. All frictional effects are negligible. In this situation, forces on the elevator are such that:
    a. The upward force by the cable is greater than the downward force of gravity
    b. The upward force by the cable is equal to the downward force of gravity
    c. The upward force by the cable is smaller than the downward force of gravity
    d. The upward force by the cable is greater than the sum of the downward force of gravity and a downward force due to the air
    e. None of the above. (The elevator goes up because the cable is being shortened, not because an upward force is exerted on the elevator by the cable).

USE THE STATEMENT AND FIGURE BELOW TO ANSWER THE NEXT FOUR QUESTIONS (17 through 20).

A rocket drifts sideways in outer space from point “a” to point “b” as shown below. The rocket is subject to no outside forces. Starting at position “b”, the rocket’s engine is turned on and produces a constant thrust (force on the rocket) at right angles to the line “ab”. The constant thrust is maintained until the rocket reaches a point “c” in space.

17. Which of the paths below best represents the path of the rocket between points “b” and “c”?

18. As the rocket moves from position “b” to position “c” its speed is:
    a. Constant
    b. Continuously increasing
    c. Continuously decreasing
    d. Increasing for a while and constant thereafter
    e. Constant for a while and decreasing thereafter

19. At point “c” the rocket’s engine is turned off and the thrust immediately drops to zero. Which of the paths below will the rocket follow beyond point “c”?

20. Beyond position “c” the speed of the rocket is:
    a. Constant
    b. Continuously increasing
    c. Continuously decreasing
    d. Increasing for a while and constant thereafter
    e. Constant for a while and decreasing thereafter

21. A woman exerts a constant horizontal force on a large box. As a result, the box moves across a horizontal floor at a constant speed “V_o”.

    The constant horizontal force applied by the woman:
    a. Has the same magnitude as the weight of the box
    b. Is greater than the weight of the box
    c. Has the same magnitude as the total force, which resists the motion of the box
    d. Is greater than the total force, which resists the motion of the box
    e. Is greater than either the weight of the box or the total force, which resists its motion

22. If the woman in question 25 suddenly stops applying a horizontal force to the box, then the box will:
    a. Immediately come to a stop
    b. Continue moving at a constant speed for a while and then slow to a stop
    c. Immediately start slowing to a stop
    d. Continue at a constant speed
    e. Increase its speed for a while and then start slowing to a stop

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

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

a. Neither student exerts a force on the other
b. Student “a” exerts a force on student “b”, but “b” does not exert any force on “a”
c. Each student exerts a force on the other, but “b” exerts a larger force
d. Each student exerts a force on the other , but “a” exerts a larger force
e. Each students exerts the same amount of force on the other

24. An empty office chair is at rest on a floor. Consider the following forces:

1. A downward force of gravity
2. An upward force exerted by the floor
3. A net downward force exerted by the air

Which of the forces is (are) acting on the office chair?

a. 1 only
b. 1 and 2
c. 2 and 3
d. 1, 2, and 3
e. None of the forces. (Since the chair is at rest there are no forces acting upon it)

25. Despite a very strong wind, a tennis player manages to hit a tennis ball with her racquet so that the ball passes over the net and lands in her opponent’s court. Consider the following forces:

1. A downward force of gravity
2. A force by the “hit”
3. A force exerted by the air

Which of the above forces is (are) acting on the tennis ball after it has left contact with the racquet and before it touches the ground?

a. 1 only
b. 1 and 2
c. 1 and 3
d. 2 and 3
e. 1, 2, and 3

Appendix K: Third Law Assessment During Unit

FCI Check 1

1. A large truck collides head-on with a small compact car. During the collision:
   A. The truck exerts a greater amount of force on the car than the car exerts on the truck.
   B. The car exerts a greater amount of force on the truck than the truck exerts on the car.
   C. Neither exerts a force on the other, the car gets smashed simply because it gets in the way of the truck.
   D. The truck exerts a force on the car but the car does not exert a force on the truck
   E. The truck exerts the same amount of force on the car as the car exerts on the truck.

USE THE STATEMENT AND FIGURE BELOW TO ANSWER THE NEXT TWO QUESTIONS (2 and 3).

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

2. While the car, still pushing the truck, is speeding up to get up to cruising speed:
   A. The amount of force with which the car pushes on the truck is equal to that with which the truck pushes back on the car.
   B. The amount of force with which the car pushes on the truck is smaller than that with which the truck pushes back on the car.
   C. The amount of force with which the car pushes on the truck is greater than that with which the truck pushes back on the car.
   D. The car's engine is running so the car pushes against the truck, but the truck's engine is not running so the truck cannot push back against the car. The truck is pushed forward simply because it is in the way of the car.
   E. Neither the car nor the truck exerts any force on the other. The truck is pushed forward simply because it is in the way of the car.

3. After the car reaches the constant cruising speed at which its driver wishes to push the truck:
   A. The amount of force with which the car pushes on the truck is equal to that with which the truck pushes back on the car.
   B. The amount of force with which the car pushes on the truck is smaller than that with which the truck pushes back on the car.
   C. The amount of force with which the car pushes on the truck is greater than that with which the truck pushes back on the car.
   D. The car's engine is running so the car pushes against the truck, but the truck's engine is not running so the truck cannot push back against the car. The truck is pushed forward simply because it is in the way of the car.
   E. Neither the car nor the truck exerts any force on the other. The truck is pushed simply because it is in the way of the car.

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

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

   A. Neither student exerts a force on the other.
   B. Student “a” exerts a force on student “b”, but “b” does not exert any force on “a”.
   C. Each student exerts a force on the other, but “b” exerts the larger force.
   D. Each student exerts a force on the other, but “a” exerts the larger force.
   E. Each student exerts the same amount of force on the other.

5. An empty office chair is at rest on a floor. Consider the following forces:
   1. A downward force of gravity
   2. An upward force exerted by the floor.
   3. A net downward force exerted by the air.

   Which of the forces is (are) acting on the office chair?

   A. 1 only.
   B. 1 and 2.
   C. 2 and 3.
   D. 1, 2, and 3.
   E. None of the forces. (Since the chair is at rest there are no forces acting upon it)

Appendix L: Second Law Assessment During Unit

FCI Check 2

1. Two metal balls are the same size but one weighs twice as much as the other. The balls are dropped from the roof of a single story building at the same instant of time. The time it takes the balls to reach the ground below will be:
   A. About half as long for the heavier ball as for the lighter one.
   B. About half as long for the lighter ball as for the heavier one.
   C. About the same for both balls.
   D. Considerably less for the heavier ball, but not necessarily half as long.
   E. Considerably less for the lighter ball, but not necessarily half as long.

2. A stone dropped from the roof of a single story building to the surface of the earth:
   A. Reaches a maximum speed quite soon after release and then falls at a constant speed thereafter.
   B. Speeds up as it falls because the gravitational attraction gets considerably stronger as the stone gets closer to earth.
   C. Speeds up because of an almost constant force of gravity acting upon it.
   D. Falls because of the natural tendency of all objects to rest on the surface on the earth.
   E. Falls because of the combined effects of the force of gravity pushing it downward and the force of the air pushing it downward.

USE THE STATEMENT AND FIGURE BELOW TO ANSWER THE NEXT QUESTION.

The accompanying figure shows a frictionless channel in the shape of a segment of a circle with center at "O". The channel has been anchored to a frictionless horizontal tabletop. You are looking down at the table. Forces exerted by the air are negligible. A ball is shot at high speed in the channel at "p" and exits at "r".

3. Consider the following distinct forces:
   1. A downward force of gravity.
   2. A force exerted by the channel pointing from q to O
   3. A force in the direction of motion.
   4. A force pointing from O to q.

   Which of the above forces is (are) acting on the ball when it is within the frictionless channel at position "q"?

   A. 1 only.
   B. 1 and 2.
   C. 1 and 3.
   D. 1, 2, and 3.
   E. 1, 3, and 4.

USE THE STATEMENT AND FIGURE BELOW TO ANSWER THE NEXT

QUESTIONS.

The figure depicts a hockey puck sliding with constant speed V_o in a straight line from point "a" to point "b" on a frictionless horizontal surface. Forces exerted by the air are negligible. You are looking down on the puck. When the puck reaches point "b," it receives a swift horizontal kick in the direction of the heavy print arrow. Had the puck been at rest at point "b," then the kick would have set the puck in horizontal motion with speed V_k in the direction of the kick.

4. Along the frictionless path you have chosen in question 8, the main force(s) acting on the puck after receiving the kick is (are):
   A. A downward force of gravity
   B. A downward force of gravity, and a horizontal force in the direction of motion.
   C. A downward force of gravity, an upward force exerted by the surface, and a horizontal force in the direction of motion.
   D. A downward force of gravity and an upward force exerted by the surface
   E. None. (No forces act on the puck)

5. An elevator is being lifted up an elevator shaft at a constant speed by a steel cable as shown in the figure below. All frictional effects are negligible. In this situation, forces on the elevator are such that:
   A. The upward force by the cable is greater than the downward force of gravity.
   B. The upward force by the cable is equal to the downward force of gravity.
   C. The upward force by the cable is smaller than the downward force of gravity.
   D. The upward force by the cable is greater than the sum of the downward force of gravity and a downward force due to the air.
   E. None of the above. (The elevator goes up because the cable is being shortened, not because an upward force is exerted on the elevator by the cable).

USE THE STATEMENT AND FIGURE BELOW TO ANSWER THE NEXT FOUR QUESTIONS (6 through 7).

A rocket drifts sideways in outer space from point "a" to point "b" as shown below. The rocket is subject to no outside forces. Starting at position "b", the rocket's engine is turned on and produces a constant thrust (force on the rocket) at right angles to the line "ab". The constant thrust is maintained until the rocket reaches a point "c" in space.

6. As the rocket moves from position “b” to position “c” its speed is:
   A. Constant.
   B. Continuously increasing.
   C. Continuously decreasing.
   D. Increasing for a while and constant thereafter.
   E. Constant for a while and decreasing thereafter.

A point “c” the rocket’s engine is turned off and the thrust immediately drops to zero.

7. Beyond position “c” the speed of the rocket is:
   A. Constant.
   B. Continuously increasing.
   C. Continuously decreasing.
   D. Increasing for a while and constant thereafter.
   E. Constant for a while and decreasing thereafter.

8. A woman exerts a constant horizontal force on a large box. As a result, the box moves across a horizontal floor at a constant speed “v_o”.

   The constant horizontal force applied by the woman:

   A. Has the same magnitude as the weight of the box.
   B. Is greater than the weight of the box.
   C. Has the same magnitude as the total force, which resists the motion of the box.
   D. Is greater than the total force, which resists the motion of the box.
   E. Is greater than either the weight of the box or the total force, which resists its motion.

9. If the woman in question 8 suddenly stops applying a horizontal force to the box, then the box will:
   A. Immediately come to a stop.
   B. Continue moving at a constant speed for a while and then slow to a stop.
   C. Immediately start slowing to a stop.
   D. Continue at a constant speed.
   E. Increase its speed for a while and then start slowing to a stop.

Appendix M: First Law Assessment During Unit

FCI Check 3

1. Two metal balls are the same size but one weighs twice as much as the other. The two metal balls roll off a horizontal table with the same speed. In this situation:
   A. Both ball hit the floor at approximately the same horizontal distance from the base of the table.
   B. The heavier ball hits the floor at about half the horizontal distance from the base of the table than does the lighter ball.
   C. The lighter ball hits the floor at about half the horizontal distance from the base of the table than does the heavier ball.
   D. The heavier ball hits the floor considerably closer to the base of the table than the lighter ball, but not necessarily at half the horizontal distance.
   E. The lighter ball hits the floor considerably closer to the base of the table than the heavier ball, but not necessarily at half the horizontal distance.

USE THE STATEMENT AD FIGURE BELOW TO ANSWER THE NEXT QUESTION.

The accompanying figure shows a frictionless channel in the shape of a segment of a circle with center at “O”. The channel has been anchored to a frictionless horizontal tabletop. You are looking down at the table. Forces exerted by the air are negligible. A ball is shot at high speed in the channel at “p” and exits at “r”.

2. Which path in the figure below would the ball most closely follow after it exits the channel at “r” and moves across the frictionless tabletop?

3. A steel ball is attached to a string and is swung in a circular path in a horizontal plane as illustrated in the accompanying figure below. At the point P indicated in the figure, the string suddenly breaks near the ball. If these events are observed from directly above as in the figure, which path would the ball most closely follow after the string breaks?

USE THE STATEMENT AND FIGURE BELOW TO ANSWER THE NEXT TWO QUESTIONS (4 through 5).

The figure depicts a hockey puck sliding with constant speed V_o in a straight line from point “a” to point “b” on a frictionless horizontal surface. Forces exerted by the air are negligible. You are looking down on the puck. When the puck reaches point “b,” it receives a swift horizontal kick in the direction of the heavy print arrow. Had the puck been at rest at point “b,” then the kick would have set the puck in horizontal motion with speed V_k in the direction of the kick.

4. Which of the paths below would the puck most closely follow after receiving the kick?

5. Along the frictionless path you have chosen in question 4, the speed of the puck after receiving the kick:
    A. Is constant.
    B. Continuously increases.
    C. Continuously decreases.
    D. Increases for a while and decreases thereafter.
    E. Is constant for a while and decreases thereafter.

6. A ball is fired by a cannon from the top of a cliff as shown in the figure below. Which of the paths would the cannon ball most closely follow?

7. A boy throws a steel ball straight up. Consider the motion of the ball only after it has left the boy's hand but before it touches the ground, and assume that forces exerted by the air are negligible. For these conditions, the force(s) acting on the ball is (are):
    A. A downward force of gravity along with a steadily decreasing upward force.
    B. A steadily decreasing upward force from the moment it leaves he boy's hand until it reaches its highest point; on the way down there is a steadily increasing downward force of gravity as the object gets closer to the earth.
    C. An almost constant downward force of gravity along with an upward force that steadily decreases until the ball reaches its highest point; on the way down there is only a constant downward force of gravity.
    D. An almost constant downward force of gravity only.
    E. None of the above. The ball falls back to ground because of its natural tendency to rest on the surface of the earth.

8. A bowling ball accidentally falls out of the cargo bay of an airliner as it flies along in a horizontal direction. As observed by a person standing on the ground and viewing the plane as in the figure below, which path would the bowling ball most closely follow after leaving the airplane?

USE THE STATEMENT AND FIGURE BELOW TO ANSWER THE NEXT THREE QUESTIONS
(9 through 11).

A rocket drifts sideways in outer space from point “a” to point “b” as shown below. The rocket is subject to no outside forces. Starting at position “b”, the rocket’s engine is turned on and produces a constant thrust (force on the rocket) at right angles to the line “ab”. The constant thrust is maintained until the rocket reaches a point “c” in space.

9. Which of the paths below best represents the path of the rocket between points “b” and “c”?

10. A point “c” the rocket’s engine is turned off and the thrust immediately drops to zero. Which of the paths below will the rocket follow beyond point “c”?

11. Beyond position “c” the speed of the rocket is:
    A. Constant.
    B. Continuously increasing.
    C. Continuously decreasing.
    D. Increasing for a while and constant thereafter.
    E. Constant for a while and decreasing thereafter.

12. Despite a very strong wind, a tennis player manages to hit a tennis ball with her racquet so that the ball passes over the net and lands in her opponent’s court. Consider the following forces:
    1. A downward force of gravity.
    2. A force by the “hit”.
    3. A force exerted by the air.

    Which of the above forces is (are) acting on the tennis ball after it has left contact with the racquet and before it touches the ground?
    A. 1 only.
    B. 1 and 2.
    C. 1 and 3.
    D. 2 and 3.
    E. 1, 2, and 3.

Appendix N: Statistical Analysis of Data

Statistical Analysis

The data comes from counting the number of correct answers for the questions pertaining to that specific law for each test. The number of correct answers was then averaged for the nine students who participated in the study. Averages were collected from the pre test, during unit test, the post test at the end of the unit, and the post test after the next unit for each of Newton's laws. A paired, single T-Test was then performed between the pre test and each of the post tests for each law.

Third Law

The third law assessment consisted of five questions that called upon students to correctly identify the concept that for every action there is an equal and opposite reaction. Table 6 shows the averages number of correct answers out of five questions for each test and the p-value obtained from the T-Test.

Table 6: Third Law Averages and p-value

Third Law						
	Pre	During	Pre	Post 1	Pre	Post 2
Ave	2.33	4.22	2.33	4.33	2.33	3.78
p-value	0.005		0.005		0.02	

As evidenced by the p-values for all of the comparisons, the students made statistically significant gains ($p<0.05$).

Second Law

For the second law assessment there were nine questions that required the students to recognize that for an object to accelerate there must be nonzero net force acting on it, conversely that if there is a nonzero net force acting on an object then it is accelerating. Table 7 shows the averages number of correct answers out of nine questions for each test and the p-value obtained from the T-Test.

Table 7: Second Law Averages and p-values

Second Law						
	Pre	During	Pre	Post 1	Pre	Post 2
Ave	2.33	3.00	2.33	3.22	2.33	3.44
p-value	0.15		0.1		0.05	

A rather interesting trend shows up in the (Table 7) data for second law. In the first two comparisons the p-values do not show statistically significant gains. However, in the comparison of the pre test to the post 2 test the numbers show an almost statistically significant gain.

First Law

The first law assessment consisted of twelve questions that asked the students to be able to understand that an object at rest will remain at rest, and an object in motion will remain in that motion, unless acted upon by an outside force. Table 8 shows the averages number of correct answers out of twelve questions for each test and the p-value obtained from the T-Test.

Table 8: First Law Averages and p-values

First Law						
	Pre	During	Pre	Post 1	Pre	Post 2
Ave	3.33	2.67	3.33	5.56	3.33	4.33
p-value	0.4		0.02		0.3	

It is interesting to note that the p-value for pre and post 1 shows a statistically significant gain, but neither the pre and during nor are the pre and post 2 even remotely close to showing a statistically significant gain.

Analysis

Upon review of the data, the hypothesis that graphical proof of Newton's laws would increase the acceptance of the laws as the operating procedure for changes in motion was supported for third law and marginally supported for first and second law. The claim that third law was successful is supported by the data in Table 6. All of the p-values in Table 6 are significantly less than 0.05, thus showing a statistically significant gain for all comparisons after the pre test. The reason that the student learning of first and second law were marginally successful is because there were statistical results that supported a gain, but not all of them supported a gain. For instance, in Table 7, the p-value for *post 2* showed a statistically significant gain but the other two p-values do not show a statistically significant gain. Like Table 7 we see that in Table 8 the p-value for *post 1* is less than 0.05, but the other two p-values are well above 0.05.

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