STUDENT MISCONCEPTIONS IN NEWTONIAN MECHANICS

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A general understanding of Newton’s first and second law is demonstrated in the literature to be severely lacking or seemingly absent in most students. While several studies found some degree of success involving experimental teaching methods in high school and college classes, this study seeks to address the foundation of students’ knowledge in Newtonian Mechanics: early education. Fourth grade and sixth grade students were first interviewed, testing for current understanding of forces and motion, and subsequently taught four lessons on the topic. Lessons were designed (based on successful classroom ideas described by the literature) to target common misconceptions students have involving forces and motion. Pre-interviews confirm the lack of general understanding of many concepts described by the literature, while post-interviews show statistically significant conceptual changes in many of the targeted conceptual areas. The lessons involved in this study successfully changed student ideas on topics involving friction, forces stopping objects’ motion (as opposed to it stopping on its own), an understanding of the different ways motion can change, and that forces are what change motion. Unfortunately, the one topic described by the literature as hardest to alter remained prevalent in the students. Post-interviews show student still answering either “the force of the push” or “some external force that would keep the object moving” when asked what keeps an object in motion. A second phase of this study (a longitudinal
study) will examine whether this particular misconception, after several years of these
lessons, can promote stronger conceptual growth.
I dedicate this thesis to my father, whose strength and courage has inspired me to achieve great things.

Also to my family including its latest addition: Linda Bylica.
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LITERATURE

Based on personal experience, anecdotal evidence, and a vast array of literature, it appears that Newtonian Mechanics one of the most misconstrued concepts in Physics. It is for this reason that many researchers have been striving for new means of conceptually moving students from a pre-17th century Aristotelian view to Newton’s scientifically accepted view of forces and motion. Much research has been done showing students at the college level (e.g., Thorton & Sokoloff, 1997 or Clement, 1982), as well as in high-school (e.g., Brown, 1989 or Thijs, 1992), have misconceptions consistent with Aristotelian mechanics, and that traditional physics classes are not successful in changing them. Researchers (e.g., Driver, 1985 or McCloskey, 1983) have inventoried the misconceptions most consistently present in students, promoting better awareness as well as creating a launching point for change in teaching strategies. Research (e.g., McDermott, 1984 or Dekkers & Thijs, 1997) has also been dedicated to discovering different ways of delivering the material in a more hands-on fashion with an emphasis on student construction of knowledge. Studies (e.g., Vosniadou et al., 2001 or Hake, 1987) have even created best practice classrooms, to test out these different classroom environments to see if they promote conceptual change. Results show differing amounts of conceptual growth due to differing teaching methods. Successful studies generally include ideas consistent with constructivist theory and research.

Studies (McCloskey, 1983) indicate students entering introductory physics classes generally begin with an Aristotelian perspective on forces and motion. Aristotle’s views on the world were derived mainly from the general philosophy and cosmology of the time. The earth was the center of the universe, the stars and planets moved in perfect
circles around the earth, and the four main elements were constructed in spheres from the center to outside the earth, being: earth, water, air, and fire (Fowler, 1995). The “natural” motion of objects was towards the sphere the object was most comprised of. When said sphere is reached, the motion is said to naturally come to rest. For example, a rock (comprised mostly of earth) would naturally want to be in the earth sphere, the lowest and closest to earth, whereas smoke (comprised mostly of air and fire) would float upwards towards the fire sphere (Daunt, n.d.). When objects were removed from their elemental sphere, perhaps by human intervention, the motion was said to be “violent” motion. Again, the tendency for the object was to want to move until it was back in its primary elemental sphere (Fowler, 1995).

Aristotelian reasoning implies many different things about the intrinsic nature of objects. In the case of natural motion, force is seen as an internal property of objects, where objects create, destroy, or alter their own internal force in attempts to get to rest in the objects’ sphere of choice (Crowell, 2003). This theory of internal force was later given the title impetus. Violent motion, however, is to do with two objects’ interactions, mainly an animal or human creating an unnatural state for the object. This implies that only living things can exert (non-natural) forces (Crowell, 2003).

A final point that Aristotle brings up in his works is best summarized as $F=mv$, where the velocity of the motion is proportional to and in the direction of the force. Also implied through this equation is the fact that if there is no force on an object, the object has no velocity (Sambursky, 1962). Stating again, much as we see in real life settings, that when a force is directing an object’s motion, the tendency of that object is to stop shortly after the force on that object stops.
To trained physicists, many of these ideas may seem foreign at times; however, there seems to be an intuitive nature to these ideas, which appear in many naïve theories of motion. McCloskey (1983) notes: “Although this basic theory appears to be a reasonable outcome of experience with real-world motion, it is strikingly inconsistent with the fundamental principles of classical physics. In fact, the naïve theory is remarkably similar to a pre-Newtonian physical theory popular in the 14th through 16th centuries.”

Clement (1982) documented this preconception in students. He accomplished this by pre-interviews conducted on thirty-four college students (eleven of which had taken a previous physics class) to inventory these misconceptions. The most revealing question asked on the survey was dubbed the coin problem. The beauty of the coin problem is in its simplicity: A coin is thrown perfectly upwards, and falls straight down. The students are asked to label the forces on the coin as it is flying through the air. The correct responses label only one force acting on the coin (gravity), whereas the incorrect responses add an upward force on the coin propelling it forwards. In his study Clement showed three of the students (12%) answering the question correctly on pre-questionnaires, leaving thirty-one incorrect responses.

This lack of knowledge is not entirely incomprehensible, without formal teachings on physics it is unlikely that the students will spontaneously generate knowledge aligned with Newtonian mechanics. Clement shows that coming into a physics class, a student’s untutored thoughts on motion tend toward the idea: force is in the direction of the motion. Clement classifies this as “Motion implies a force [in the direction of the motion]”. This explanation is most common when students are faced
with a situation where there is a force opposing the motion. Students tend to invent a propelling force that will exceed the opposing force, and continue the motion forward. That force will die out as the object moves forward until the opposing force balances it out, whereupon the object changes direction.

McDermott (1984) provides overviews for many conceptual barriers for students. While her article does include a classroom study of conceptual change, her inventory of these barriers more importantly adds to Clements’s (1981) study of preconceptions in physics, and what is to be done to address them. In her study, she immediately acknowledges the preconceptions involved with forces and motion as not easily overcome. She indicates that these preconceptions are not readily abandoned, but often retained alongside of the science conceptions. The word force has both a scientific and everyday use that may be compounding these preconceptions.

Ideally, teachers strive to move these current Aristotelian conceptions into the more scientifically accepted direction: Newtonian Mechanics. Almost two-thousand years after Aristotle, in 1679, Newton published *Philosophiae Naturalis Principia Mathematica*, in which he defines his three laws of motion, diverging almost completely from Aristotle’s long-standing view (Wilson, 1996). The first law, summarized, reads: objects keep moving or stay stopped unless acted upon by an external force, conflicting with Aristotle’s view that forces cause motion and objects tend towards rest states.

Newton’s second law (simplified: $F=ma$), differs mathematically as well as conceptually from the previous $F=mv$. The motion is not created by a force, but changed by the application of a force. Lastly, when a force is applied to an object, the object exerts an equal force in the opposite direction onto the article applying the force, contrasted to
Aristotle’s view where force is mostly an internal entity, shifting inside the object to accommodate the object’s nature. The goal of physics classes is to shift physics students from the more intuitive Aristotelian view to the more scientifically accepted Newtonian view.

Thornton and Sokoloff (1998) studied a “traditionally run” physics class, in which these Aristotelian misconceptions were originally present in as many as 90% of the students. They tested for changes in misconceptions after a normal semester of physics as well as a specially prepared lab section complementing the lecture. The study consisted of a roughly 500-student lecture hall at the University of Oregon. Half of the students in this lecture hall decided to take the lab section of the course, while half opted out of the laboratory section. This put the researchers in a unique situation in that they could control most outstanding variables normally dealt with in education studies (i.e., teacher personality, or student variations from class to class). All students were given a standardized conceptual physics test called the Force and Motion Conceptual Evaluation (FMCE) both before and after taking the class. This pre and post-test procedure was a standard in most of the studies on conceptual change in physics.

The half of the students not taking the lab showed little conceptual gain on many of the questions specifically targeting misconceptions on forces. After a “well executed” traditional lecture hall conceptual gains averaged 7%. Post-test results showed less than 20% of the students with answers consistent with Newtonian mechanics. Specifically, the understanding of the coin problem (as mentioned by Clement, 1982) moved from 10% to 20% after a semester’s course on introductory physics.
A study by Emarat, Arayathanitkuk, Soankwan, Chitaree, and Johnston (2002) follows up on Thornton and Sokoloff (1998) showing similar results. College students at multiple universities were given the FMCE both before and after standard college level introductory physics classes. Their results after these surveys showed similar conceptual gains to Thornton and Sokoloff (1998): only 10% gains after a semester of introductory physics. This study also concluded, “few students entering a university understand force and motion from the Newtonian point of view,” (Emarat et al., 2002), begging the question: *What was their education like before the college level?*

High school has its own version of introductory physics in which students study what normally takes a semester at the college level through an entire year. High school studies have been conducted along the same lines as the college surveys: a series of questions is asked both before and after a physics class. Brown (1989) used his own conceptual physics problems, focusing on questions involving Newton’s third law to test for possible change in his students’ understanding. Initial results show, expectedly, 1% to 20% correct answers on the pre-questions. After a year of physics however, students answer between 5% and 50% accurately. One problem in particular shows a bowling ball rolling down an alley and hitting a pin. The students are asked when the two collide, which one has more force acting on it. The question moved from 1% to 5% correctness over the year’s course. While, this question is specifically asking about Newton’s third law, the lack of conceptual gains involving Newton’s laws are solidly still there, even in a high school setting. Brown concludes by saying that the persistence of student’s impetus preconceptions has lead him to believe teaching from the perspective of Newton’s third
law, where forces are interactions between two things will help students move away from
force as an innate property of single objects.

Tracing these preconceptions back further, studies have examined junior high and
elementary students for the existence of these preconceptions. Driver et al. (1985)
surveys many of these academic articles concerning children’s education and physics
misconception, finding consistencies in the misconceptions children have concerning
forces and motion. Her research indicates five major misconceptions present in many of
the articles surveyed. The first misconception, seen mostly in younger children states
that forces have to do with living thing. Many times it is seen that students will associate
living properties with forces, speaking of how objects use force to fight their way against
the will of gravity.

The thought that constant motion requires a constant force has been studied to a
great extent. Initial studies of 13-year-olds show this misconception strongly imbedded.
Studies trace through high school students all the way up to college honors physics
students. Uniformly, this misconception has been reported. “More advanced students are
simply better equipped to verbalize their impetus theories than less advance students”
(Driver et al., 1985).

Third, and corollary to the second: the amount of motion is proportional to the
amount of force, or F= m v. From this line of thought follow the fourth and fifth
misconceptions. If a body is at rest, the body has no force acting on it, and if the body is
moving, it has a force acting on it in the direction of the motion. These themes rules
seem to be the most common misconceptions present in children based upon surveys of
academic articles concerning forces and motion.
Researchers have asked and wondered about where the preconceptions originate. Researchers (e.g., Terry, Jones & Hurford, 1985) have suggested that the everyday experience creates these preconceptions, but other researchers have gone as far as to investigate primary school teachers for their conceptions of forces and motion. Preece (1997) surveyed physics and non-physics teachers by inviting them to grade makeshift tests to see if they marked off for force arrows indicating impetus theory. Of the physics teachers surveyed, 60% correctly crossed out the arrow, where less than 30% of the non-physics teachers followed suit. Pre-service teachers were polled in the same fashion, yielding 70% correct responses for physics pre-service teachers, and less than 4% for non-physics pre-service teachers.

An alternate study by Kruger, Palacio, and Summers (1992) of over 450 teachers finds similar results. Of the teachers involved, all taught science to children ages 5 to 11. In the situations presented to the teachers, friction was missed 63% of the time, the normal force as much as 50% of the time, and weight 60% of the time. Questionnaires were also administered, indicating that virtually none of the primary school teachers had a fully correct view of instances involving force and motion. As many as 91% of the teachers were found to agree with statements resembling the Aristotelian view of internal force: impetus. These results give additional perspective on misconceptions students have going into an introductory physics course.

Teaching and teacher technique becomes increasingly important when dealing with conceptual barriers. Many of the studies previously mentioned, had their own personal philosophy on how to best correct these issues. Some researchers have designed their own class to test these pedagogical theories.
Thornton and Sokoloff (1998), for example, designed their own lab to test against their control group’s conceptual gains of nearly 10%. The lab, which they titled Interactive Laboratory Demonstrations, was (as its name implies) an interactive, demonstration-based lab setting. The results of this added lab course show close to 70% of the students correctly answering conceptual questions, with as much as 55% conceptual growth, showing interactive lab settings can successfully alter student conception’s on Newtonian Mechanics.

Other innovations in teaching strategy also place a large emphasis on the lab structure for most content knowledge. A study done by Hake (1986) at Indiana University redesigned a lab section of a class towards a Socratic dialogue methodology, where the teacher prompted student discussion on topics juxtaposed with hands-on experiments to either confirm or deny ideas on mechanics. The labs were constructed to cause disequilibrium in the students, forcing them to discuss the discrepancies and remodel their concepts towards a more scientific perspective. The class, with the guidance of the teacher, then decided which explanation was most consistent with the lab. This, mixed with videotapes from The Mechanical Universe (emphasizing a historical perspective on force and motion) yielded 32% conceptual growth (from 41% pre-test to 73% post-test) in mechanics. The pre-test in this case, as well as an analysis of student body, shows an overall higher achieving student body present in this study, which may account for the high initial scores, as well as the conceptual gains. This, however, does not discount the use of the disequilibrium and constructivist dialogue as a mean of reestablishing conceptions.
Dykstra, Boyle, and Monarch (1992) discuss the creation of disequilibrium through use of discrepant events as a main device of lab investigations. The goal is to find a phenomenon that may seem like it has an obvious outcome, but when tested, differs significantly from the predicted outcome. They then propose to have a group discussion, with a teacher who more facilitates the discussion than resolves it. The students must then test their ideas for validity, and come to a final conceptualization of the event. Gorsky and Finegold (1988) discuss this methodology through use of computer simulations. The simulations they have developed are meant to simulate discrepant events in which students attempt to answer. While they regard their software as important, they acknowledge the fact that short computer sessions can’t change such deeply embedded beliefs, and are meant to be accompanied by teacher interaction.

Thijs’ (1992) study actually attempted use of discrepant events as a main device of an experimental classroom, which was designed to promote constructivist learning. This classroom, a five-week secondary school course on mechanics, prompted students to work together, in groups, to construct their own knowledge of physical situations. The idea behind this method of teaching is the students will be posed discrepant events, and have to discuss and debate the event with their group to come to (after some discourse) a group conclusion. The teacher, through this, doesn’t take sides, but asks questions to students, hopefully prompting further discussion. By the end of the course it was apparent that not only the typically higher achieving students were learning, but a wide range of students had flourished in this type of class. Unfortunately, while some of the students embraced this kind of class, other students were left feeling frustrated by the course. Changes in learning through the class showed a 28% increase for situations
where the object was at rest, but only a 10% increase for situations where the object was in motion. From these numbers it was concluded that this course was not effective in remedying impetus misconceptions, though generally successful in other areas including weight and normal force. A follow up to this study (Dekkers & Thijs, 1997) attempted constructivist learning in a classroom setting for a second time yielding higher pre to post test results. This time the research indicates an increase of 47% after a similar, but slightly modified constructivist course.

A comprehensive study by Vosniadou, Ioannides, Dimitrakopoulou, and Papademetriou (2001) draws upon research done on promoting conceptual change using good learning environments to create its own experimental classroom. The study looks at the conceptual change of student in two different fifth and sixth grade classrooms over an entire semester of an introductory mechanics course. The class regarded as the control received regular instruction (as specified in the National Curriculum), whereas the class deemed experimental group was taught using research recommendations of good learning environments. In the experimental classroom children were encouraged to think and discuss things with each other as opposed to with the teacher. This promoted a more cooperative learning environment, where the class worked as a group to try to understand the material. Also, teachers decided to concentrate on fewer areas of physics and cover topics with greater depth. This is quite different from the United States education systems where a greater breadth of material is covered, but only at surface level. When the teacher approached a topic where many misconceptions lie, he or she made the students aware of the misconceptions, and stressed the more complete model of the situation. This study attempted to foster a change in the concept as opposed to extinguish
the previous conception and overwrite it with another. Vosniadou et al. believed that the
students would show more motivation and aptitude to learn the material if the previous
ideas were not overwritten, but extended upon.

The pre-test and post-test results showed remarkable gains in students’ conceptual
understanding. The first of four questions asking students to label forces acting on a rock
sitting on the ground show the experimental pre to post test results of 12% to 50% correct
response in comparison with the control groups pre to post test results of 11.8% to 0%
respectively. The next three questions show similar results, where the number of correct
responses for the experimental group was statistically significant, whereas the gains for
the control group were not significant. While 50% of the students is still fewer than most
teachers want to see, the gains reported by this study (of 5th and 6th graders) were huge in
the area of conceptual change of forces and motion, especially for students so young.

Age becomes an increasingly important factor when studying children, and their
attainment of concepts. Piaget (1929) described the development of children as four
discrete stages. The gap between the second (Preoperational) stage and the third (concrete
operational) stage comes around when the child is seven. It is at that point the student
develops systematic and logical thought, opening the door to new genres of information.
This knowledge, however, has only to do with concrete situations. Abstract information
processing comes around when the child is 11, when he or she reaches the formal
operational stage. At this point, the child has all the cognitive flexibility of a full grown
adult. Pauen (1996) has seen and studied this effect using force vectors to test students of
different ages ability to synthesize two vectors into resultant motion. As Piaget (1929)
described, abstract objects, such as vectors do not compute until the formal operational
stage; up to age 10 wrong solutions predominated her research. When she attempted the same test, only using figures of people pulling as opposed to the force vector, answers to the questions asked showed first through fourth graders answering mostly correctly on each of the questions asked. This fact encourages a shift from abstract concepts (such as forces vector) to more concrete examples (i.e. people pulling) to convey the same information to younger audiences.

Some literature (Osborne & Wittrock, 1983) has cautioned against teaching concepts prone to misconceptions too late in students education, mentioning that topics left to later grades may become impenetrable to the students. Crosgrove and Forret (1992) call this a loss of plasticity. A study conducted by Palmer and Flanagan (1997), however, refutes these suggestions. By testing students ages 11 and 12 against students ages 15 and 16 for conceptual gains, researchers attempted determine which group would overcome their “force-implies-motion” misconception more frequently. After reading student centered texts discussing the topic, students were asked to answer some question centered on the misconception. The 11 and 12-year-old students show conceptual change 35% of the time, where the 15 and 16-year-old students show conceptual gains 44% of the time. The results show no support to the notion of loss of plasticity, as the differences in percentage between the two age groups were not significant. Concept attainment seems to be semi-uniform, suggesting neither (or both) times are the “right times” to broach the topic of Newtonian Mechanics. One questions left unanswered by this study, as well as the studies above: what is the effect of lessons at both early and late years of a child’s education? Will 11 and 12-year-old students do better than 44% conceptual gain when they reach 15 and 16-years-old?
SETUP OF STUDY

This study seeks to answer three questions on the nature of children’s ideas of forces and motion. First, what are student current conceptions of forces and motion? Second, can teaching lessons early in a student’s career change those current conceptions to more closely resemble the “Newtonian perspective” on forces and motion? Finally, how will many years of these lessons affect students’ progress towards the “Newtonian perspective”? The scope of this thesis can only account for the first two questions, as the last requires a longitudinal study far beyond the breadth intended for this paper. It, however, does set the stage for the longitudinal study, giving fundamental information as to students’ current ideas on motion and the ease in which they might change.

Students through their education are taught a sequence of lessons beginning at kindergarten and continuing up until they are seniors in high school. The subjects of these are mandated by the State of Ohio, described as Academic Content Standards. The sequence of these standards relating to forces and motion can be found in Appendix 8, describing, in detail, what students should conceptually understand at each grade of their academic career. To test for the current conceptual knowledge as well as possible change that may occur, Kenwood Elementary School was enlisted to provide a base of research subjects through the study. Relations with teachers as well as students have been fostered at this school (by the PRISM program and by Dr. Van Hook) in order to give this study ample research subjects, as well as classroom time to conduct this study. While kindergarten, first, second, fourth, and sixth grade have been selected to be a part of this study, time constraints have made it possible only to report research conducted with fourth and sixth grade students. First and Second grade lessons are currently being
conducted, and results are still being collected. Preliminary results will be available for the Defense on Friday. HSRB approved consent forms were distributed and teaching times secured before the opening interviews of this study.

Interview protocols were created to best answer to the first question posed by this study. The questions involved in the protocol focused on the retrieval of students’ current ideas of motion, as well as possible misconceptions the student may have. Much like Thorton & Sokoloff’s (1997) FCME test, many of the questions were designed to target common misconceptions students have regarding forces and motion. However, unlike Thorton & Sokoloff’s (1997) paper pencil questionnaire, this study conducted verbal interviews, leaving questions more open ended for the student to decide how to answer. A copy of the interview protocol can be found in Appendix 1.

People not associated with the teaching of the lessons conducted interviews. This was meant to prevent biases, where student remembrance of ideas taught in the lessons could be provoked by the presence of the person who taught them the information. During the interviews, the interviewer took notes of student answers. In addition to this, sessions were tape-recorded and later transcribed for a more detailed account of proceeding. It was useful that both methods were utilized, as tape recorder sessions were sometimes lost to dying batteries and background noise, and interviewer notes were at times incomplete. Both techniques, in conjunction, served to provide a complete perspective on students’ ideas on forces and motion. The full interview procedure was conducted with all participating students before any lessons were taught to the classes.

After pre-interviews were completed, four approximately 50 minute lessons were taught by members of the study through the course of a week on topics concerning forces
and motion. The sixth grade students covered multiple topics, including an introduction to Newton’s first law, Friction, Gravity, and Air resistance (Appendices 2, 3, 6, and 7). The idea was to introduce Newton’s first law and look at multiple situations where it may apply. After sixth grade lessons were complete, post-interviews indicated more time needed to be spent on the concepts behind Newton’s first law, and less on the individual forces that work within it. Fourth grade lessons were subsequently changed to leave more room for expansion on Newton’s first law. This lessons series included an introduction on Newton’s first law, friction, friction again, and a closing day in which the children played a game, which consolidated Newtonian thoughts (Appendices 2, 3, 4, and 5). The two sets of lessons described above are detailed in Appendices 2-7, giving full details of the lessons.

Once lessons were taught, post-interviews were conducted to give a comparison of what the students knew and what knowledge they acquired from the lessons. Interviews were conducted in the same fashion as previously described, using the same questions and protocol described in Appendix 1. This was done to control for variables that may be present through differing formats of questions, giving a direct comparison between previous thoughts, and current conceptions.
COLLECTIVE PROCESS OF STUDENT IDEAS OF MOTION

Interviews done before the experiment serve to determine student ideas of motion before any formal lessons on the subjects of forces and motion have been taught. These interviews were recorded and analyzed to establish, generally, what ideas student hold on many of the areas where misconceptions are present. A coding system was designed to suit the purposes of collating data from verbal exchanges into a more quantitative form. Based on the answers given, a mark was awarded to each area of possible misconceptions, being: changes in motion, force causing changes in motion, why an object slows down, why an object keeps moving, gravity, air resistance, and friction.

Changes in motion (Table 1), including speeding up, slowing down, and changing direction, were tabulated by looking at references to the items when asked “How can you change how an object is moving?” or “What are ways that motion of an object can change?” Answers such as stopping and starting were placed in the slowing down and speeding up category respectively.

The fact that force causes a change in motion was one of the primary concepts being taught through the lessons. To properly identify full conceptualization (Table 2), two areas of the interviews were looked at. First, when the interviewer asked, “what causes a change in motion?” student responses should have been either force, push, or pull. Second, when the interviewer threw a ball up into the air, and asked “did the motion of the ball change?” students should have responded yes, and when asked “what causes change in motion?” force gravity, or the earth were considered correct responses. To get fully correct interpretation students had to have answered all parts of this correctly. Otherwise, students received either partial answers described as: “Forces Change Motion
but Failed Gravity Example” or “Force Changes Motion Absent where Gravity Example Intact.” If both were absent, student responses were awarded a “Neither Example Correct” mark.

Why an object slows down (Table 3) is of particular interest, as it distinguishes between students with an Aristotelian worldview (where objects stop on their own) and a Newtonian worldview (where something must be acting on an object to stop it). To correctly answer this, the student, when asked “Did the object slow down on its own, or did something make it slow down and stop,” had to have acknowledged that something slowed the object down. Correct answers to this question were unclear as to what the student thought may have slowed the object down. Answers to what caused the object to slow down came in later sections of this tabulation. If a student answered the more Aristotelian answer: the object slowed down on its own, an incorrect response was recorded. If student conceptions could not be discerned from the information gathered through the interview, the mark fell in the category “unanswered”.

Students, with more frequency than expected, tended to first answer that something slowed the object down, but when asked specifically “Did the object slow down on its own or did something slow it down and stop?” they concluded that the object slowed down on its own. This gave rise to the “both” category, as both answers appeared in their responses, leading researchers to believe students were unsure and therefore meriting an incorrect mark.

Aristotelian impetus was acknowledged by Thijs (1992) as a particularly hard misconception to change and therefore was looked at closely by this research. Students were asked multiple times what is keeping the object going after the interviewer has let
go of the object (Table 4). This was asked in the context of sliding a block across a table, rolling a ball across a table, and (much like Clement’s 1982 coin problem) a ball being thrown into the air. Correct responses included variation of “objects in motion stay in motion” and “nothing is propelling it forward.” Incorrect responses were grouped into two categories. If students responded that the object was moving because of an external force, (e.g. gravity or air) or an internal force (e.g. your push was keeping the object moving) it was marked incorrect in its separate category. If student conceptions could not be discerned from the information gathered through the interview, the mark fell in the category “unanswered”.

Gravity, air resistance, and friction (Tables 5-7) were considered “good” if students used the word correctly as well as defined it correctly. If a definition was missing from the explanation, the response was awarded a “good use, no definition” mark. This category was the most encompassing, as both students who didn’t know the definition of the word, and students who were not asked to define certain words were grouped into this category. The interviewer was supposed to ask for definitions when the vocabulary word was used in the interview, but many times the interviewer simply did not. If the word or use of the definition was absent from the interview, the response was grouped into the absent category.

A final category was created to acknowledge student explanation of words, which deviated entirely from common definitions of the word. For example, a typical response when asked about gravity was that air was pushing down on us, causing us to be stuck to the earth. An answer such as this one was marked “alternate conception” as the student offered a definition of a word, though it deviated from common scientific explanation of
gravity. Air resistance was commonly misconstrued as weight when asked why paper was floating to the ground, where friction, at times, was defined as air resistance slowing an object down. All of these examples fell into the alternate conception category.

These seven categories constituted the areas that not only cover the extent of the lessons conducted by this study, but also report student ideas on targeted misconceptions. Analyzing these areas gives researchers a quantitative idea of frequency of thoughts in pre-interviews, leading to conclusions of the preconceptions students have entering both a 4th and 6th grade class room.
STUDENT PRECONCEPTIONS

The areas described above were established based on reoccurring themes in student preconceptions. Many times when several students indicated similar answers to a question, it became a category in the collective process described above. Student preconceptions in the areas of forces and motion were established exclusively by these pre-interviews and tabulated by the quantitative collective process.

Fourth grade students correctly mentioned both slowing down and changing direction 45.5% and 50% respectively, however speeding up was only mentioned 18.2% of the time. This was similar with the sixth graders, as 31.5% indicated slowing down, 57.9% changing direction, but only 15.8% speeding up.

Students consistently missed one aspect of the two-prong test when asked about forces changing motion. Few (13.6% fourth grade, and 36.8% sixth grade) answered both areas correctly. The majority of student got one of the two areas correct leaving, again, few student who failed to answer either section correctly.

Based on previous Aristotle logic described by Daunt (n.d.), this study’s protocol asked if something stops the object or if the object stopped on its own. 31.8% of the fourth graders reported correctly that something slows the object down, as well as 36.8% of the sixth graders. Unfortunately, this indicates most of their reasoning still lies somewhere closer to Aristotelian reasoning than its Newtonian counterpoint.

The idea that objects require a force (internal or external) to maintain their motion was reported by Driver (1985) to be one of the main preconceptions students possess. This was confirmed by the results, as not a single sixth-grader (0%), and only one (4.5%) fourth-grader adequately answered that objects in motion will continue in motion.
Gravity was one of the most widely and correctly used terms. While the term was used correctly, it became apparent, through follow up questions, that students did not understand where gravity came from, or even how it works. 9.1% of the fourth graders and 5.2% of the sixth graders correctly used and defined gravity. However, many (68.2% and 47.3% respectively) of the students not fully defining gravity, still used it to correctly in situation posed to them.

Air was used and described correctly 54.5% and 31.5% by fourth and sixth graders to describe the difference between a crumpled up and flat piece of paper. Found just as commonly was the misconception of weight making the difference between the two pieces of paper. Most of the student who used the term air used it correctly.

Friction was understood and used correctly by 40.9% of the fourth graders and 36.8% of the sixth graders. Subjects that used the word friction correctly defined the word when prompted. Most commonly, however, friction was absent from most explanations of situation. This could follow from the “object stops on its own” logic.

Other areas of general student idea were found, and qualitatively recorded as part of this study. These examples were not seen enough to merit a quantitative counterpart, though are worth mentioning as student preconception.

Many times students (especially in the fourth grade) would give one-word answers to complex questions. These words were generally generated from a pallet of science vocabulary they had heard through the years, but incorrectly used in the context of the question, which indicated either sloppiness of answers or simply not being aware of meaning of said science vocabulary.
Generally when asked questions such as “what keeps the block moving after I let it go?” students were inclined to invent a cause that would keep the block moving. It was obvious that many of the students had never thought of questions such as the ones asked by the protocol, and therefore tended to devise answers as opposed to answering, “I don’t know.” The inventiveness of some of these answers indicated a general lack of understanding, but also an amount of willingness to attempt to explain different physical concepts never broached by their thoughts.

In general, it was apparent that most of the concepts were lacking in some way or another, and the academic content standards for the fourth and sixth graders had not been satisfactorily fulfilled. Further instruction was needed before further conceptual gains would ensue.
LESSONS PLANS

Based on this information previously discussed, lessons have been created to target the common misconceptions present in students as well as utilize some of the teaching methods discussed in the previously mentioned articles. The lessons were structured around the 5 E model of lesson planning for science instruction (Bybee & Landes, 1988). The five E’s, which make up this lesson planning structure include: Engage, Explore, Explain, Extend and Evaluate.

The Engage phase is meant to get the kids interested in the topic as well as get them thinking about the topic. The Explore and Explain are positioned in this sequence so students will explore the topic before the teacher engages in any formal instruction to the students. The idea behind this reasoning is students will come up with their own explanation of the content before the teacher get to interject any formal explanation of the material. Research indicates (Gagne, 1985) that students will retain information better if they first experience it for themselves as opposed to being directly told the material. The teacher (during the Explain phase) then goes back and formalizes the content the students just experienced for themselves. The Extend phase is meant to give students another chance to interact with the material, now with the formal knowledge they were given, and the Evaluate phases is meant to test their newly gained knowledge.

Through these lessons, three main points were to be established to the students: forces change motion, object’s motion can change by speeding up, slowing down, or changing direction, and objects should continue moving or stay stopped unless acted upon by a force. Secondary to that was the concept that certain forces that may cause these changes in motion being: friction, gravity and air resistance.
Sixth grade lesson plans were structured as four major lessons: an overview of Newton’s first and second law, a lesson on friction, a lesson on gravity, and a lesson on air resistance. The first lesson (Appendix 2) was based on the use of discrepant events such as the one described by Dykstra et al. (1992) to illicit conceptual growth. A board was fixed with magnets and a metal ball was rolled down creating an abnormal path. Students were asked to try to reproduce the path of the ball using straws and blowing balls rolling across the ramp. Through some frustration the students experienced many of Newton’s laws as well as the concept that changing motion requires force.

Lessons involving the discovery of friction, gravity, and air resistance followed in the next three days of lessons (Appendices 3, 6 and 7). The idea behind all of these lessons was each student was given an opportunity to experience each force for him or herself, and discuss it with their group. Much like as described in Thijs’ (1992) study, students were to discuss their thoughts amongst themselves and come to ideas as a group. The role of the teacher was not to give answers to the students, but to elicit discussion between the students so as to move their ideas towards the more scientific direction.

Once groups came to a consensus, the teacher leads a class discussion of the results of each experiment. Much like what was described by Hake (1986) as the Socratic method, each group is forced to prove their conclusion to the best extent possible, while the teacher facilitates this discussion. A classroom consensus is established, and the teacher fills in any conceptual gaps that are missing from the discussion, as well as names for concepts the students do not yet have names for. Vosniadou et al. (2001) broadly discusses the general idea behind this form of classroom,
which he designates as “cooperative learning.” Students work together to learn the material, as the teacher facilitates the discussion process.

After sixth grade lessons were completed a qualitative look at post-interviews indicated more time needed to be spent on the concepts behind Newton’s first laws, and less on the individual forces that work within the law. It was decided that the fourth grade lessons would focus more closely on Newton’s first and second law and less on Air and Gravity.

Lessons one and two (Appendices 2 and 3) remained the same for the fourth graders, where lesson three and four were changed to focus more closely on Newton’s laws and less on the forces that act within it. Lesson three (Appendix 4) was a closer look at friction and how it satisfies Newton’s first law (despite the fact that it appears as though the object stops on its own), and lesson four (Appendix 5) was a review of Newton’s law through a game where students were prompted to interact in a fully Newtonian world. The students involved in the fourth grade study were firmly in Piaget’s (1929) concrete operational stage. The students of this age can engage in logical reasoning, but only involving concrete examples. This was also a factor in the use of games as teaching tools as well as the decision that air resistance and gravity were to be removed from the lesson series, as their intangibility could prove troublesome for students of this age.

The hands on and interactive environment established by these lessons are meant to promote the kind of long term conceptual growth indicated by most current science education research. Students exposed to the 5E experimental setups, and led to discover physical concepts for themselves will hopefully not only gain the conceptions intended,
but retain them for years to come. By establishing three main points, and discussing topics in ways students can fully comprehend (for their age bracket) lessons are meant to convey difficult concepts to students in the fourth and sixth grade. After lessons were complete, post-interviews were analyzed to determine the effects of these lessons on students’ conceptual understanding.
POST-INTERVIEW RESULTS

Post-interviews were done in the same fashion as pre-interviews: a one on one dialogue, with questions targeting areas where student misconceptions were prevalent. With the exception of one additional question (as indicated in Appendix 1) the post-interview protocol was the same as the pre-tests. Student interviews were compared to previous conceptions to establish changes in ideas about forces and motion. These results were then compacted into the quantitative version of the data, with the exact procedure as described in the previous section: Collective Process of Student Idea of Motion.

Many of the students reported ways that an object’s motion can change (Table 1) with greater frequency than in pre-interviews. Fourth grade post-interviews exemplify this as all three different changes in motion (speeding up, slowing down, and changing direction) were mentioned much more frequently than in the pre-interviews. Sixth grade interviews show less of an effect, though this could be due to complications with the interview process.

Sixth grade post-interviews show a lower frequency of changes in motion reported. This was due to problems with interviewer questionings. While the protocol requires asking the question “What are the ways an object’s motion can change?” one of the interviews involved in this study consistently failed to ask this question, making reporting reasonable results on the area difficult. As his interviews account for nearly half of the sixth grade post-interviews, caution is to be taken when looking at the data involved in this area.

Most striking about these results is the fact that student may have previously mentioned some of the changes in motion, but more often than not students enumerated
the three ways an object's motion can change, as if directly recalling classroom lessons. This is apparent from the evening out in the numbers of changes in motion reported. In the pre-interviews, students mentioned changing direction and slowing down more frequently than speeding up. However, in post interviews students reported all three roughly equally. Fourth grade post-interviews report 13 (56.5%), 13 (56.5%), and 16 (69.6%) for speeding up, slowing down, and changing direction (respectively). Sixth grade was similarly even with 7 (31.8%), 8 (36.4%), and 6 (27.3%) reporting the changes in motion.

The test for force implying changes in motion (Table 2) shows dramatic increases from pre to post-interview results. Students were able to verbally connect force with changes in motion as well as answer the example situation correctly. 14 (60.9%) fourth grade students and 15 (68.2%) sixth grade student were able to do both in post-interviews.

To the question does something stop the object, or does it stop on its own (Table 3), there was a remarkable increase in correct answers. Fourth grade interviews show 17 (73.9%) students answering that something stopped the object, and sixth grade interviews show 15 (68.2%). At times, students had to think hard about this question, as the quicker answers was “the object stops on its own.” It takes a moment’s consideration to come to the correct answers. A quote from a sixth grade post interview shows this change in reasoning:

*Interviewer*: “Did the block slow down and stop on its own or did something make it slow down and stop?”
Impetus (Table 4) was a topic that the best research studies were unable to divert. Thijs’ (1992) study directly states that while there were many conceptual gains through the study, it failed to relieve the impetus misconception in its students. The results were similar. While there were small gains between pre and post-interviews, they were nominal, with a great majority of the student still not fully understanding the concept.

Fourth grade shows four (17.4%) students with a Newtonian concept of motion, and sixth grade with only one (4.5%) who understood that objects in motion stay in motion. Again, these results were unfortunate, but not unexpected (based on previous research into the topic indicating the difficulty with remedying the impetus misconception).

The overwhelming extent of this misconception became apparent to this study as the teacher who was kind enough to lend her classroom interjected her thoughts during one of the lessons. In her words:

“When you exert the force on the billiard ball to push the billiard ball up in the air…that means: there is more force going up on the billiard ball than there is a force of gravity, so the forces are unequal. Until, eventually the force on the billiard ball and the force of gravity are equal [and the ball stops in mid air]…”

Much like what was described by Kruger et al.’s (1992) survey of teachers, the teacher this study had been working with had thoughts that existed outside of the Newtonian concept of the way forces and motion work! It was not surprising that many of the
students involved in this study had incorrect conceptions, as the person who they had been studying science with every day since the beginning of the year had the misconceptions as well. It was at this point in the study that the extent of the misconception became strikingly apparent, making the work to be done by this study increasing crucial.

Results involving friction (Table 5) were remarkable. 19 (82.6%) of fourth grade students and 17 (77.3%) of the sixth grade students demonstrated a great understanding of friction. This was most likely due to the extra time that was spent on the topic during the lessons. It was apparent that the increase in correct friction answers were directly related to an increase in correct answers the question “does the object stop on its own or does something stop it?” Both areas dramatically increased from pre to post-interviews. Qualitatively speaking, the converse was true as well: the few people who failed to mention friction also were the students who answered that the object stops on its own.

Gravity (Table 6) and air resistance (Table 7) were not directly taught in the fourth grade lessons, so the 2 (8.7%) and 12 (52.2) people who answered these questions correctly on the post interview did so from their own personal experience with the topic.

Sixth grade gravity (Table 6) post-interview results were unclear. Gravity was used and defined correctly twice (9.1%) in post interviews, though many times in the interview students would use the term correctly, but the interviewer would fail to ask what gravity was or where it came from. This lead to many of the answers ending up in the “correct use, no definition category. Including the 16 (72.7%) students who correctly used the term but were sometimes not asked to define, the total of correct gravity answers totals 18 (81.8%). While it is unclear if any of the students had a proper definition of
gravity in mind, it is definite that the student’s awareness of gravity as a force went up from 10 in the pre-interview to 18 in the post-interview. Due to a need for consistency, only the word with a definition was considered correct, and results show nominal gains.

Air resistance (Table 7) showed relatively good increases in correct answers submitted for sixth grade students. 12 students (54.5%) answered the item correctly in the post-interview. Due to a relatively short time (25 minutes in a class period) being spent on air resistance, the results were expectedly lower than the results achieved with friction and other areas where more time was spent.

With these interviews, there were some qualitative results that appeared. These results did not merit their own category, but do deserve some discussion.

Some students, when asked what is motion would reply “force.” Indicating they had learnt the word “force”, but connected it with motion and not changes in motion. This is similar to Driver’s (1985) version: F=mv. Students who answered this generally also failed to answer questions concerning impetus correctly.

During the post-interviews, many of the answers shifted from intuitive responses to more learned answers. As opposed to thinking about different real life examples of motion, students began to describe what they thought was the science answers to the questions. For example, when asked what are the ways motion can change, instead of answering things like running and turning, or jumping up and down, students listed the three ways motion can change and ended their answer. It was obvious that the lessons had an effect on the students, as many of their answers were direct quotes from the lessons. Getting science answers to question posed was a good start, but more
importantly was the question: were students using these science terms correctly in the context of the question, indicating conceptual growth from pre to post-interviews?

To completely answer this question, the chi-squared algorithm was used to test the significance of the changes between pre and post-interviews. The fourth grade (Table 8) and sixth grade (Table 9) chi squared results were calculated from the previous tables (Tables 1-7). Changes in motion were added up as a total of all three, so results included all the “speed up” answers, all the “slow down” answers, and all the “changes direction” answers as one number to be calculated. Significance was considered as less than a 5% p-value result.

Fourth grade results considered statistically significant include: changes in motion, force implies change in motion, something slows an object down, and friction. Results not statistically significant include: Objects in motion stay in motion, gravity and air resistance. Once again, it was expected that air resistance and gravity results were not significant, as neither topic was broached by the lessons. Sadly impetus continued to be a problem with students.

Sixth grade results falling in the statistically significant category include: Force implies change in motion, something must slow an object down, and friction. Areas that were not statistically significant were: changes in motion, objects in motion stay in motion, gravity, and air resistance. Change in motion results were muddled simply by the lack of asking the question, which begs the answer. Impetus was once again an issue with students, despite the direct involvement with the issue. Also, gravity and air resistance were lacking, probably due to their short involvement with the topic.
EDUCATIONAL IMPLICATIONS

State grade level indicators have been placed at certain location in a student’s academic career based on decisions made by the Department of Education and the committee of teachers, science educators, and parents that worked to create the standards document. An implied matter imbedded in the research question: “what are students’ current conceptual understandings” is the concern that students are not understanding “the changes when an object experiences a force (e.g., a push or pull, weight and friction)” by the third grade (Ohio Department of Education, 2003). This research indicates that most students in the fourth and sixth grade do not have a basic foundational understanding of Newtonian Mechanics by the time the state indicates they should. This striking information implies that teachers are either systematically teaching the material incorrectly, the material is not receiving enough time during the year’s science curriculum, or the state standards are not developmentally appropriate at the times in a child’s education that they are being taught. This research has shown that several changes may increase the likelihood of conceptual understanding.

The conceptual changes shown by this study indicates that with some amount of depth, student understanding of Newtonian Mechanics can be significantly strengthened. Conceptual areas in this study that have received more time from the lessons showed the strongest and most significant gains. Areas that had shown little initial conceptual understanding, such as the fact that push and pull (force) causes a change in motion (a Kindergarten indicator), showed close to 50% gains in the fourth grade when some amount of time was spent on the subject. Currently, Newton Mechanics is receiving scattered lessons in Kindergarten, First, and Third grade, and showing little conceptual
understanding by the time students reach Fourth grade. One way of achieving this without spending too much added time on the subject would be to condense the three indicators dealing with Newton mechanics into one year (perhaps in the fourth grade) where all the indicators can be met with a series of lessons not unlike the ones described by this thesis. Much like the curriculum pattern described by Vosniadou et al (2001), the added depth may help strengthen student understanding significantly, without spending too much overall time on Newtonian Mechanics. This format for constructing the indicators will most likely show stronger student conceptions in the area of forces and motion.

It was initially a concern of this study that the state indicators were developmentally inappropriate at the grade levels which they were placed. Research from this study, however, indicates that with well-constructed lessons and some time spent on the topic, these lessons are comprehensible to both concrete and formal operational thinkers. Shifting possibly formal operational ideas (such as friction) down to more concrete operations concepts (such as rubbing) one can elicit strong conceptual changes in younger age groups. This paired with best practices (as described by the literature), can transform seemingly developmentally inappropriate indicators into tangible lessons to concrete operational thinkers.

Kruger et al. (1992) indicates that many K-6 teachers are conceptually lacking in Newtonian mechanics. It is important for teachers to understand, with great detail, the subject that they are teaching. This will not only help them better communicate the material but prevent them from passing on misconceptions to their students. A possible extension of this study would be not only writing up the lessons, but supplementing them
with an in depth content supplement, that not only describes Newtonian Mechanics, but the misconceptions that lie within. Currently, there is no state requirement for K-3 teachers to have a physics course during their preparation. This added content knowledge may increase the likelihood of typical misconceptions to be overcome and taught correctly in the appropriate age groups.

Researcher from this study merged with the literature in the field most strongly supports the idea that with some time and a thought out setup of lessons, the ideas of Newtonian Mechanics can be successfully taught to concrete and formal operational thinkers. It is important that the teachers understand the misconceptions present in this field of physics to correctly convey the concepts to the students. It is also equally important that the standards are condensed to better present Newtonian Mechanics in an in depth fashion, connecting all idea as one big concept: forces and motion.
CONCLUSION

Seeking to understand children’s current concepts of forces and motion, as well as our ability to change them over the course of four lessons involving Newton’s laws, this study has uncovered that children typically do not initially understand forces and motion from a Newtonian perspective. Pre-interviews established that a majority of the current student body is conceptually lacking in the several areas targeted by this study. After lessons were administered, conceptual gains were seen in areas involving friction, objects stopping by some force, understanding the different changes in motion, and that forces are what change motion. These statistically significant gains were seen in area where the lessons focused most strongly. Concurrent with the literature, however, an understanding that objects in motion stay in motion was strongly lacking, even after lesson were taught directly on the topic. Most students (greater than 80%) still held to some form of impetus theory, or invented a force, which would keep an object moving after it has been pushed. The last phase of this study involving many years of these lessons with the same students has yet to answer the question: can this conception be changed in a greater student body?
TABLE 1

CHANGES IN MOTION

<table>
<thead>
<tr>
<th></th>
<th>4&lt;sup&gt;th&lt;/sup&gt; Grade Pre-interview: n=22</th>
<th>4&lt;sup&gt;th&lt;/sup&gt; Grade Post-interview: n=23</th>
<th>6&lt;sup&gt;th&lt;/sup&gt; Grade Pre-interview: n=19</th>
<th>6&lt;sup&gt;th&lt;/sup&gt; Grade Post-interview: n=22</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed Up</td>
<td>4 (18.2%)</td>
<td>13 (56.5%)</td>
<td>3 (15.8%)</td>
<td>7 (31.8%)</td>
</tr>
<tr>
<td>Slow Down</td>
<td>10 (45.5%)</td>
<td>13 (56.5%)</td>
<td>6 (31.5%)</td>
<td>8 (36.4%)</td>
</tr>
<tr>
<td>Change Direction</td>
<td>11 (50.0%)</td>
<td>16 (69.6%)</td>
<td>11 (57.9%)</td>
<td>6 (27.3%)</td>
</tr>
</tbody>
</table>
## TABLE 2

<table>
<thead>
<tr>
<th>FORCE CAUSING CHANGES IN MOTION</th>
<th>4th Grade Pre-interview: n=22</th>
<th>4th Grade Post-interview: n=23</th>
<th>6th Grade Pre-interview: n=19</th>
<th>6th Grade Post-interview: n=22</th>
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<tbody>
<tr>
<td>Forces Change</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Motion with Correct Gravity</td>
<td>3 (13.6%)</td>
<td>14 (60.9%)</td>
<td>7 (36.8%)</td>
<td>15 (68.2%)</td>
</tr>
<tr>
<td>Example</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forces Change</td>
<td>1 (4.5%)</td>
<td>4 (17.4%)</td>
<td>2 (10.5%)</td>
<td>3 (13.6%)</td>
</tr>
<tr>
<td>Motion but Failed Gravity</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Example</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Force Changes</td>
<td>11 (50.0%)</td>
<td>3 (13.0%)</td>
<td>8 (42.1%)</td>
<td>3 (13.6%)</td>
</tr>
<tr>
<td>Motion Absent where Gravity</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Example Intact</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neither Example</td>
<td>7 (31.8%)</td>
<td>2 (8.7%)</td>
<td>2 (10.5%)</td>
<td>1 (4.5%)</td>
</tr>
<tr>
<td>Correct</td>
<td></td>
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TABLE 3
WHAT SLOW THE OBJECT DOWN?

<table>
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<tr>
<th></th>
<th>4&lt;sup&gt;th&lt;/sup&gt; Grade Pre-interview: n=22</th>
<th>4&lt;sup&gt;th&lt;/sup&gt; Grade Post-interview: n=23</th>
<th>6&lt;sup&gt;th&lt;/sup&gt; Grade Pre-interview: n=19</th>
<th>6&lt;sup&gt;th&lt;/sup&gt; Grade Post-interview: n=22</th>
</tr>
</thead>
<tbody>
<tr>
<td>Something</td>
<td>7 (31.8%)</td>
<td>17 (73.9%)</td>
<td>7 (36.8%)</td>
<td>15 (68.2%)</td>
</tr>
<tr>
<td>Slows Object Down</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Object Slows Down on its own</td>
<td>7 (31.8%)</td>
<td>3 (13.0%)</td>
<td>8 (42.1%)</td>
<td>7 (31.8%)</td>
</tr>
<tr>
<td>Both Answers Given</td>
<td>7 (31.8%)</td>
<td>3 (13.0%)</td>
<td>4 (21.1%)</td>
<td>0 (0%)</td>
</tr>
<tr>
<td>Unanswered</td>
<td>1 (4.5%)</td>
<td>0 (0%)</td>
<td>0 (0%)</td>
<td>0 (0%)</td>
</tr>
</tbody>
</table>
### TABLE 4

**WHAT KEEPS THE OBJECT IN MOTION?**

<table>
<thead>
<tr>
<th></th>
<th>4th Grade Pre-interview: n=22</th>
<th>4th Grade Post-interview: n=23</th>
<th>6th Grade Pre-interview: n=19</th>
<th>6th Grade Post-interview: n=22</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Nature of Objects Motion</strong></td>
<td>1 (4.5%)</td>
<td>4 (17.4%)</td>
<td>0 (0%)</td>
<td>1 (4.5%)</td>
</tr>
<tr>
<td><strong>Internal Force</strong></td>
<td>13 (59.1%)</td>
<td>14 (60.9%)</td>
<td>10 (52.6%)</td>
<td>12 (54.5%)</td>
</tr>
<tr>
<td><strong>External Force</strong></td>
<td>5 (22.7%)</td>
<td>2 (8.6%)</td>
<td>8 (42.1%)</td>
<td>9 (40.9%)</td>
</tr>
<tr>
<td><strong>Unanswered</strong></td>
<td>3 (13.6%)</td>
<td>3 (13.0%)</td>
<td>1 (5.3%)</td>
<td>0 (0%)</td>
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</table>
### TABLE 5

**FRICTION**

<table>
<thead>
<tr>
<th></th>
<th>4th Grade Pre-interview: n=22</th>
<th>4th Grade Post-interview: n=23</th>
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TABLE 6

GRAVITY

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<td>(4.3%)</td>
<td>(36.8%)</td>
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TABLE 8
FOURTH GRADE CHI-SQUARED TEST RESULTS

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TABLE 9

SIXTH GRADE CHI-SQUARED TEST RESULTS

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<td>2.183</td>
<td>0.0697</td>
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REFERENCES


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http://www.faqs.org/docs/Newtonian/Newtonian_100.html


http://galileoandeinstein.phys.virginia.edu/lectures/aristot2.html


Ohio: Author.


from Rochester Institute of Technology Web site:

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APPENDIX A.

ELEMENTARY MOTION INTERVIEW PROTOCOL

Student ID ___________________ Teacher: ____________________

Interviewer __________________ Date ___________ Time ___________

- Please state the student’s ID at the beginning and at the end of the interview for
  the tape recorder. As the student if it’s okay if you ask him or her some questions
  about science and record it with the tape recorder. (If he/she says no, then end the
  interview there.)
- Be sure that you and the student speak loudly enough that the microphone picks
  up your voices. If the child speaks softly, please repeat their responses verbatim
  for the recording.
- Tell the students that it’s fine if he/she wants to draw a picture as part of his/her
  explanation (have paper and pencil available for the students). Write the question
  number and student ID on any picture.

1. What is motion? What do you think of when you hear the word motion?

2. How can you change how an object is moving? What are ways that motion of an
   object can change?

3. POST-INTERVIEW ONLY: [Show the steel ball and place the wooden
   platform with the embedded magnet on the table.] I’m going to roll this ball along
   this board. How do you think it will move? [Record what they indicate. Then roll
   the steel ball and note their reaction.] What happened? What could have caused
   that to happen?

4. [Show students a ball at rest on the table] What do I need to do to make this ball
   start moving along the table?
[Do what they describe to the ball.] What is keeping the ball moving right now? [Be sure to ask while the ball is still moving!] Is something pushing on it?

Will the ball roll forever (if the table went on forever)? If not, why will it slow down and stop? Does it stop on its own or does something slow down and stop it?

5. [Show the student a block at rest on the table.] What do I need to make this block start moving along the table? [Do what they describe to the block.] What is keeping the block moving after I let go of it? [Be sure to ask while the block is still moving!] Is something pushing on it?

[Once the block stops, ask:] Did the block slow down and stop on its own or did something make it slow down and stop? [If something made it stop, ask:] What made it slow down and stop?

6. What is something that we could do that would make the block travel farther. [If say, push harder or start it faster, ask for another way that doesn’t require changing how you start it moving.] Why do you think that would work?

7. What is something that we could do that would make the block travel less far (slow down and stop sooner). [If say, push less or start it slower, ask for another way that doesn’t require changing how you start it moving.] Why do you think that would work?
8. [Push both ball and block so they move across the table.] Why was the ball able to move farther than the block across the table? [If says, “it rolls”, then ask how does rolling make it easier for the ball to move farther?]

9. [Show ball initially at rest on a ramp. Release ball.] What made the ball start moving? [If says ramp, ask how does the ramp start the ball moving.]

10. [Toss ball straight up in the air.] What made the ball start moving upwards?

   Is the ball’s motion changing while it’s in the air? How is its motion changing? What is causing the ball’s motion to change (while it’s in the air)?

11. [Pick up a crumpled piece of paper and let it fall to the ground] What is making the paper start moving downwards?

   [Pick up both a flat sheet of paper and a crumpled sheet and let them fall at the same time] What is different this time than the last time I made the piece of paper fall? Why was this one slower than the other? What was acting on the paper to change how fast it moved?
APPENDIX B.

FOURTH AND SIXTH GRADE LESSON PLANS DAY 1: INTRODUCTION TO NEWTON’S 1ST LAW

Engage: Roll regular ball across table. “I brought a ghost with me” Show students the metal ball with magnets under the table. Do this three times over three paths, (the trick is to roll the ball at different velocities to produce different effects) one where the ball is deflected, one where the ball stops, and a last one where the ball does crazy odd stuff. Ask the students what they notice, and to draw the path on the board. Cite a ghost as what made the ball act as it did.

Explore: Ask the students “how did that just happen? Separate the class into groups and give them each a billiard ball and a straw. I theorize that the ghost used wind to push the balls the way he did, so”… Tell them that you’re giving them that they get a straw, which they can use to blow on a billiard ball to reproduce what they saw the ghost do. Because you (the teacher) didn’t touch it will your hangs (besides getting it rolling in the first place) they aren’t allowed to use their hands. Have students make a “game plan” using the page from their book copying down the path they are trying to reproduce, and where to position their straw to create that motion. Give the students only one chance to produce each of the 3 paths to ensure thinking about straw positioning ahead of time. Have each student draw what happened for each of the 3 trials on the next page of their book, being as truthful as possible to the balls motion.
**Explain:** Come back together with the students and ask each group to report on what they found. “How did you do trying to reproduce the path?” “How did you change the balls motion?” (Blowing on the ball) …”How was the balls motion changed?” (Slowed down, stopped, and changing direction) Draw one of each student’s trials on the board. For each situation, draw an arrow representing which way the student had to blow to get the ball to do what it did. Tell them that the thing they described are called force. In today’s case the force we were exerting was the force of air. Tell them that forces act on things and influence the way things move (referring to their list), and they can change things motions, they can make things go faster, slow down, stop, or even start moving (as in the case with our experiment today) In fact, a man named Isaac Newton came up with rules for how things move…he says that all things motion should stay in motion (which includes things at rest)…That is unless one of these forces acts upon them.

If what Newton said was true, what was weird about what you saw today (the object moved without anything “acting” on it)? “Were you able to reproduce my results?” Do you think there could have been a force involved that made the object move as it did? What could that force have been? What you should all be asking yourselves is: what made the object move as it did? Go over some ideas the kids have (other than a ghost) that may have moved the ball the way it did. Finally it is safe to show them how you did the trick. “There was a magnet acting on it…the magnet exerted a force on the ball.”

**Extend:** Bring out the bowling ball asking them if they can change the motion by exerting force from a straw…hold for laughs. Ask them how they would change the
motion, or how hard it would be. Its motion will keep going in the same direction (with the same speed) unless a <large> force is exerted ...just like Newton said. Line up in the hall and have the kids roll the ball back and forth to see the ball start and stop.

Hint: while bowling ball is being passed around, be obnoxious narrating all the ways the motion is changing. Hearing “speed up, slow down, and change direction” over and over again helped students remember the information.

**Evaluate:** Have students fill out the first few pages of their book (in groups) and come back together and discuss their answers. Formalize “speed up, slow down, change direction” and fill the first three open ended sentences on the next page.

**HW:** Ask students to think of 2 situations where motion is changed (labeling the force that is exerted, and what is exerting that force) or a situation where objects keep their motion constant. Have them draw a picture (or write a paragraph) describing these situations.

**Key ideas:**

- Forces change motion
- Newton’s first: An object should keep moving or stay stopped unless a force changes its motion.
Take home message: forces change motion, change in motion requires a force acting on it; if motion changes, then something must be acting on the object (exerting a force) – even if we can’t see what’s exerting the force.
APPENDIX C.
FOURTH AND SIXTH GRADE LESSON PLANS, DAY 2: FRICTION

Engage: Go over homework papers on changing motion, making sure to ask students how the motion was changed (of the 3: speed up, slow down, and change direction) and what causes the change in motion. Let's do it one more time...slide not-on air puck across the table. “Wait, what’s happening...?” Show the students the block sliding across a table as your example of a violation of Newton’s law. “If Newton’s law of motion is true, how does this happen?” Brainstorm with class different ideas of what could be acting with the block to make it stop. Write on board their ideas. If ideas other than friction come up, satisfy them in some way...tell them that we will be getting into those topics later.

Explore: What about this friction thing (hoping they come to that idea) what do you mean by friction? I’m making something move, and it is coming to a stop. What is going on? Should the block keep moving forever? Is a ghost coming in and stopping the block from moving? What is messing with its motion (forces)?

Let’s explore the rubbing thing. What is the difference between the ball rolling and a block rubbing? Have them test by rolling their ball on their arm and sliding a block across their arm. Get to the idea of rubbing as a force. “Is there more or less rubbing from sliding to rolling?” The ball rolls a lot because it’s not rubbing much, where the block IS rubbing. If needed...pull out: Rubbing hands together for friction for another
perspective on the idea. “So, this rubbing thing is slowing objects down…what does that mean, if something slows something down?” acknowledging the list of ways that an objects motion is changed discussed earlier (pointing to it if you have to). It means it’s a force. Have students think of different situations where friction causes a change in motion (trying to get to situation where friction speeds up, slows down, and changes direction of objects). This is a good time to stress that forces are an interaction between two things, as it is a very physical interpretation of this concept.

Have students slide balls against arms again, this time comparing pressing ball hard against wrist versus pressing down lightly. “Is there more or less rubbing if you press softer? What if you pressed softer than that? And softer than that? What about if the two object rubbed so lightly, they weren’t touching at all?”

**Explain:** What happens to this object (hovercraft) if it wasn’t pressing into the table? Run hovercraft experiment to show Newton’s law in action again. First show puck mostly stationary, so student will believe that it’s not the fan producing its motion. Lets students pass the puck around for a little while to get used to the motion, and ask “how far should if go (using Newton’s law) if there was no rubbing force acting on it?” Send the puck down the hallway and let it go as far as it will go. It’s truly impressive how far this puck will go without any help; so let it do its thing. Come back into the room and ask students what the saw, and have them explain it to you.
Hint: anytime you’re changing the puck’s motion make it verbally explicit. It may get annoying, but I think it’s helpful for the students to hear all the different ways the motion is changing while it’s happening.
APPENDIX D.

FOURTH GRADE LESSON PLANS, DAY 3: FRICTION 2

Explore: Have students split up into different groups and give each group a block, 2
different surfaces (both sides of the board). Have them create their own experiment to
“prove to you” which surface has more friction, using a block. Make each group explain
their method before handing them the materials for the experiment. Once you approve
the experiment, the students can run their experiment to “prove” which surface has more
or less friction. From experience, the sooner you collect the materials the less goofing off
there will be. Walk around and ask groups how it’s going, and remove the materials once
groups are done. Groups can work on the next pages in their book about friction when
they are done.

Explain: Come back to center. Talk about each groups results ranking the 2 surfaces on
the board and discussing why they thought what they did. Ask them again what is
stopping the block from moving. What is slowing it down? They should say something
about the roughness of the surface, or maybe use the word friction. Talk to them about
how Newton’s law is still working even though it doesn’t seem like it. Mention that there
is a force acting on the block that makes it stop. The rubbing of the two surfaces (or
friction, if they came up with the word) is making it stop.

Extend: What would happen if I had a surface that was smoother than ice and sent a
block down it? What about a surface smoother than that? And smoother than that? If
we found a surface that has no rubbing force (or friction) what would happen if we sent the block down it? Remind students of the air puck, that it’s a similar case to a frictionless surface. (Students at this point should get that it does satisfy Newton’s law, in the an object would move forever...discuss this idea)

Evaluate: If students haven’t already finished the few pages in their book, have them do it now or for homework.

Key idea:

• Friction: two things rubbing together cause things to slow down, speed up, or change direction, which means it is a force.

• Forces can be used to stop things too, Even though things appear to be stopping on their own, there is generally a force involved slowing the object down.
This lesson functioned as the cap off for day 4 of the fourth grade class. It was a game that we played to get the class thinking in the Newtonian world. The class never got to friction or air resistance, so directly after friction, we did this.

I first handed out the last sheet of their book, which had a picture of Newton saying is “objects keep moving or stay still unless acted upon by a FORCE!” I asked the kids if they recognized that statement, and both classes came up with Newton’s first law of motion. Then, I said I need a Newton (the entire class volunteered). I had the Newton come up, and stand still in front of the class. “Now Newton here is our object, and s/he is currently standing still. What does Newton say about objects standing still? (They will keep standing still) Unless what? (Acted upon by a force)” The person answering that question was allowed to come up and be the force. “So what are you going to do? (Push or pull) How are you going to do it? (With my hand, I’ll blow on Newton, etc.) How are you gong to change Newton’s motion? (Speed up, slow down, and change direction)” After defining what the force was, I had the student exert a force on Newton. I let Newton decide how he/she was going to react to the force. I asked them what they did afterwards and why. If the student kept moving until they hit the wall, they did it right and I followed up with “what did you notice, why did Newton move that way”, if they stopped during the simulation, I asked the class if there was anything that we could change about the way Newton moved and why. I had the two run the situation again to
demonstrate it to the class, this time narrating the entire experience. Something like:

“Newton isn’t moving, so he will stay stopped until what? (A force acts on) So, what is the force going to do, it’s going to speed him up until, the force lets go, and stops acting on Newton. Then what will happen? (He will continue moving in the same direction at a constant speed) Until what? (He is acted upon by another force) Like the wall for example.” I decided to narrate everything that was going on in the game to make it annoyingly explicit exactly what was going on. I repeated the same thing with new Newtons and multiple forces (trying to make sure we get at least one speed up/slow down/ and change direction. At the most advanced stage of this game I had a student narrate what was going on.

**Cap off dialogue:** When motion gets changed, I want you all to think to yourself: what is changing the motion? Because, as Newton said: things don’t just come to a stop for no reason, and things just don’t start moving for no reason. There always has to be something there to change the motion…and I’ll tell you right now, it’s not a ghost, it’s a force. We explored different forces, such as air resistance, gravity, and friction…all things that may very well mess with motion. So, again, always ask yourself what could be changing that motion.
Friction 2

Explore: Have students split up into different groups and give each group a block, 2 different surfaces (both sides of the board). Have them create their own experiment to “prove to you” which surface has more friction, using a block. Make each group explain their method before handing them the materials for the experiment. Once you approve the experiment, the students can run their experiment to “prove” which surface has more or less friction. From experience, the sooner you collect the materials the less goofing off there will be. Walk around and ask groups how it’s going, and remove the materials once groups are done. Groups can work on the next pages in their book about friction when they are done.

Explain: Come back to center. Talk about each groups results ranking the 2 surfaces on the board and discussing why they thought what they did. Ask them again what is stopping the block from moving. What is slowing it down? They should say something about the roughness of the surface, or maybe use the word friction. Talk to them about how Newton’s law is still working even though it doesn’t seem like it. That there is a force acting on the block that makes it stop. The rubbing of the two surfaces (or friction, if they came up with the word) is making it stop.
**Extend:** What would happen if I had a surface that was smoother than ice and sent a block down it? What about a surface smoother than that? And smoother than that? If we found a surface that has no rubbing force (or friction) what would happen if we sent the block down it? Remind students of the air puck, that it’s a similar case to a frictionless surface. *(Students at this point should get that it does satisfy Newton’s law, in the an object would move forever…discuss this idea)*

**Evaluate:** If students haven’t already finished the few pages in their book, have them do it now or for homework.

**Key idea:**

- Friction: two things rubbing together cause things to slow down, speed up, or change direction, which means it is a force.
- Forces can be used to stop things too, Even though things appear to be stopping on their own, there is generally a force involved slowing the object down.

**Gravity 1** (done quickly at the end of the friction 2 lesson)

**Engage:** Hold hand out and tell students that you are going to change this ball’s motion: you are going to speed the ball up. Drop the ball and let it fall to the floor. The ball sped up…what does that mean? *(There is a force acting on it)* What caused the ball to suddenly speed up?
**Explore:** Discuss the possible things that could be making the ball fall down, hopefully they will say/know the word gravity even if they don’t know how it works exactly. Follow up with “what is gravity, how does it work?” Have students talk in groups, and fill out page titled gravity with their definition of gravity, and an explanation of how it works. Discuss with students afterwards, and come to a class definition of what gravity is and how it works. Make sure to remind them that forces are interactions between things, to give them a hint at describing gravity.

**Explain:** I personally feel that describing that all matter attracts other matter is the best way to convey gravity to the students. It begs the question, if I’m attracting all the things in the room, why can’t I feel it? You can then go into that idea that you need a lot of mass before you really start to see the effects of gravity; things need to have the mass of moons and planets before gravity starts to become noticeable.

**Extend:** Ask students “what about before I dropped the ball? Was gravity still acting on the ball before I dropped it?” When I did this I asked the student as a class, and took hands (time was constrained). If I had more time and did it again, I’d have groups discuss this question, and come to an answer with an explanation. Groups can then present their answer to the class, and discuss results. Without the group work, my guiding questions were: “If gravity was acting on it, why was it not moving...shouldn’t it be speeding up? Why, or how is it not moving (I’m holding it up with my hand)? Is that a force as well? (Yes) So forces can act against each other?
**Explain:** Show students a free body diagram with force up labeled hand and force arrow down labeled gravity. “Notice how the two forces balance each other out...if one of the two were out of balance, the object would start in the motion of the stronger force. So, if gravity is always acting down on us, what do we need to do to not constantly be falling or sinking into the ground? (a force acting up on us) Tell the student that they see this everywhere around them, the desks acting up on their books, the floor acting up on them.

**Evaluate:** Have students fill out the page in the book titled gravity, correcting their definition if necessary.

**Key idea:**
- Gravity is caused by the earth pulling on all things causing their motion to change
- Gravity is a force.
APPENDIX G.

SIXTH GRADE LESSON PLANS, DAY 4: GRAVITY 2 AND AIR RESISTANCE

**Engage:** Recap situation yesterday, having students explain it once again, why the ball is falling when I let go of it, and why it is staying still when I’m holding on to it. Use a free body diagram to illustrate the point. So, let try a new situation…show overhead of the arc path of ball. Throw the ball up, making it clear that the situation on the overhead is the same as you throwing the ball up in the air.

**Explore:** Ask, what forces are acting on the ball for each of the 4 spots in the path of the ball. Time permitting; let the students fill out the diagram for themselves (in their groups) reminding them that forces are interactions between two things, and so when things aren’t interacting with the object that they don’t exert a force.

**Explain:** Discuss student thoughts (using the overhead) on what forces were acting in the different positions of the ball. Start with the “in hand” situation first (as they are most familiar with it) and work to the “in air” situations. Ask students “Once the ball leaves your hand, your hand is there a force on the ball (other than gravity). “How is the ball still moving upwards if there isn’t an upward force on it? Can force act opposite the motion? (Yes) Where have we seen a situation where force acts against the motion (the first day, where the ball was moving forward, and students were blowing in the opposite direction to slow the ball down).”
Extend: Thought experiment: If gravity were to be turned off, what would happen to the ball if I threw it up in the air? (The ball would keep moving up, in a straight line forever, until something exerts another force on the ball)

Note: during these discussions, take the time to emphasize the point that there is no such thing as internal force…that the ball is flying upwards because of an interaction between my hand and the ball exerting a force (exerted by my hand) and should continue upwards. It is, however, acted upon by a force that slows it down, changes its direction, and speeds it up.

Evaluate: Have students finish up page in book, making sure they have the physics explanation of the ball flying through the air. If you wish, have the students come up with motion jokes for the next and final class.

Air Resistance

Engage: Show students a piece of paper. Crumple it up and let it drop to the floor. Ask them: What made this paper move (force of gravity)? Show the students, now, a similar piece of paper, but this time don’t crumple it up. Let it glide to the ground. “Now, that was the same kind of paper…what was the difference between the first time I dropped a piece of paper and this time (it was slower the second time)? Why was that? Was a ghost coming to the piece of paper and slowing it down? (Hopefully by this point we
have trained them to ask the question: “what is changing the motion?”…If not: What is changing the motion?)

**Explore:** Give the students a chance to explore this situation for themselves with two pieces of paper. The page in the book can function as a lab sheet for this experiment. Come back together and discuss their findings. The students may come up with the size being the main factor. If that is the case show them different experiments where the paper if folded up different ways and test those against each other. Keep pushing them to the idea of “what is changing the motion?” or if they need a hit “what is getting in the way of the paper?” Lead them to the idea that air is what is causing a change in the motion. Have them come up with ideas of where they have felt the force of air in their lives: bike riding, in the car, flying a kite, on a boat, etc.

**Explain:** So, when you’re riding your bike, and the wind is blowing against you, is it easier or harder to go on your bike? What about if the wind was with you, blowing on your back…easier or harder? What about if there was no wind at all? (Some kids might say it’s no difference, some might say harder) Well, if you were riding on your bike with a huge parachute or sail behind you, still no wind…easier or harder? Would you call air a force? What about if it’s not even moving, but when you are moving…is it still a force (make sure they all say yes to this). What do you think about the situation I presented you: the two pieces of paper? What is changing their motion? So, if I get what you’re telling me right, air can both speed things up, and slow things down...how would you all feel about calling it a force? Does it change motion…heck yeah.
**Evaluate:** again, the pages in the book will function as an evaluation of their progress. Also, having the class come up with motion jokes can serve to test their views on motion.

**Main Concept:** Air can be a force, and therefore can change things motion

**Conclusion of lessons:** When motion gets changed, I want you all to think to yourself: what is changing the motion? Because, as Newt non said: things don’t just come to a stop for no reason, and things just don’t start moving for no reason. There always has to be something there to change the motion…and I’ll tell you right now, it’s not a ghost, it’s a force. We explored different forces, such as air resistance, gravity, and friction…all things that may very well mess with motion. So, again, always ask yourself what could be changing that motion.
APPENDIX H.

OHIO ACADEMIC CONTENT STANDARDS DIRECTLY INVOLVING FORCES
AND MOTION

Kindergarten: Investigate ways to change how something is moving (e.g., push, pull).

Grade 1: Investigate a variety of ways to make things move and what causes them to change speed, direction and/or stop.

Grade 3: Identify contact/noncontact forces that affect motion of an object (e.g., gravity, magnetism and collision)
Predict the changes when an object experiences a force (e.g., a push or pull, weight and friction).

Grade 8: Explain that an unbalanced force acting on an object changes that object's speed and/or direction.

Grade 9: Demonstrate the ways in which frictional forces constrain the motion of objects (e.g., a car traveling around a curve, a block on an inclined plane, a person running, an airplane in flight).

Grade 12: Use and apply the laws of motion to analyze, describe and predict the effects of forces on the motions of objects mathematically.

(Ohio Department of Education, 2003)