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A Guide to Motion and Newton's Laws for General Science

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ABSTRACT

A GUIDE TO MOTION AND NEWTON'S LAWS

FOR GENERAL SCIENCE

by

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This project provides activities in motion and Newton's Laws of motion. Besides instructions on how to perform the activity, a list of student self-assessment questions is provided to encourage further inquiry. The activities are also aligned with the Essential Academic Learning Requirements for the State of Washington. These activities are designed to supplement curriculum already being taught.

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Chapter I

Background of the Project

Introduction

As a teacher of Physical Science at the high school level, I have observed that many students have trouble grasping the basic concepts of motion as defined by most physicists. For example, the idea of inertia, that objects will continue to move without a force being applied. Newton's Third Law of interacting forces is often quoted but when asked to apply the law few see that in the interaction of two objects if one moves there still is equal but oppositely directed forces between the two objects. Even the basic concepts of velocity and acceleration are not well defined in the students' minds. Despite many well-intentioned experiments, demonstrations, and explanations many students continue to believe in ideas that have been abandoned by scientists. Several educators in the field of physics have noted their students have the same problems. They believe this may be because teachers have ignored the students' previously held system of beliefs (Arons, 1990; Clement, 1982; Gang, 1993; Hammer & Schifter, 2001; Heller & Finley, 1992; Hestenes, Wells, & Swackhamer, 1992; Osborne & Wittrock, 1983; De Posada, 1997; Trowbridge & McDermott, 1980). Many of these preconceptions are common to human history as noted by Halloun and Hestenes (1985). Before Galileo most people said that objects were endowed with something called Impetus or invented forces to explain way cannon balls continued to move. We can't dismiss these ideas as mistakes but must see them as the background against which current ideas of motion must be taught. Unfortunately, methods used to teach physics concepts, for the most part, have not been successful. As Robin Woods (1994) states," Clearly, there is no simple procedure for 'teaching away' students' misconceptions. Conceptual change appears to require an ongoing solution" (p. 35).

One of the ways this change may take place is to have the students construct their own framework of knowledge that includes the concepts that have been proven to work. The idea is to present the students with situations that challenge their current concepts while encouraging them to develop an understanding of the current concepts of physics. As pointed out by Dr. Lillian McDermott (1991),

> The student mind is not a blank slate on which new information can be written without regard to what is already there. If the instructor does not make a conscious effort to guide the student into making the modifications needed to incorporate new information correctly, the student may do the rearranging. In that case, the message inscribed on the slate may not be the one the instructor intended to deliver. (p. 305)

The products of science have changed the face of modern society and students will be called upon in coming years to make decisions concerning the application of new products. The American Association for the Advancement of Science [AAAS] (1993) believes,

> The terms and circumstances of human existence can be expected to change radically during the next human life span. Science, mathematics,

> and technology will be at the center of that change - causing it, shaping it, responding to it. Therefore, they will be essential to the education of today's children for tomorrow's world. (p. XI)

The need to educate students in science so they can make these decisions wisely is also reiterated by the National Academy of Science [NAS] (1996)

> In a world filled with the products of scientific inquiry, scientific literacy has become a necessity for everyone. Everyone needs to use scientific information to make choices that arise every day. Everyone needs to be able to engage intelligently in public discourse and debate about important issues that involve science and technology. And everyone deserves to share in the excitement and personal fulfillment that can come from understanding and learning about the natural world. (p. 1)

Need for the Project

Most of the efforts have been to observe and develop curriculum for college students (Hestenes, 1992; Reif,1995; Van Heuvelen, 1991). Specifically, Hake (1992) created the "Socratic Dialogue Inducing" labs for his college classes. The work that led to the publication of *Physics by Inquiry* (McDermott, 1996) was conducted at the University of Washington. The few that dealt with high school concentrated on Physics courses. Hestenes, Wells, and Swackhamer (1992) used a pretest and posttest to assess the curriculum they were developing. Only Gang (1993) was specifically doing work at the middle school level. There are a lot of collections of exercises to demonstrate motion but few that give the kind of follow-up questions that can be used to guide the students thinking. These include *Hands-on Physics Activities with Real Life Applications* (Cunningham & Herr, 1994) and *Practical Activities or Strengthening Your Teaching of Physical Science Concepts* (Guenther, 2001).

Purpose of the Project

The purpose of this project is to put together a handbook of examples that may be used by teachers to supplement their current instruction. These examples include activities and demonstrations with questions designed for student self-assessment. They will also be aligned with the Essential Academic Learning Requirements of the State of Washington (Washington State Commission on Student Learning [WSCSL], 1998).

Definition of Terms

Common Sense. As defined by Halloun and Hestenes (1985), "common sense is a codification of experience providing meaning to our natural language" (p. 1056)

Constructivism. This is the view that, "All students must construct their own concepts, and the knowledge they already have (or think they have) significantly affects what they can learn. The student is not viewed as a passive recipient of knowledge but rather as an active participant in its creation"(McDermott, 1990, 305)

Model. The development an explanation of a variety of situations using of a group of rules that are proven to be valid (Hestenes, 1992, p. 732)

Preconception. The ideas and concepts held by students develop before formal instruction (Clement, 1982, p. 66).

Preconceptions / alternative conceptions (P / AC). A term used by Dr. Su Gang to describe the concepts that are held by students prior to formal instruction that are not compatible with current scientific concepts (Gang,1993, p.414).

Qualitative Knowledge. The concepts and ideas that form the knowledge that is behind the formulas used in science (Clement, 1982, p. 66).

Quantitative Knowledge. The use of formulas to describe physical situations (Clement, 1982, p. 66).

Socratic pedagogy. A method of teaching physics using questions to guide the students' thinking leading to students asking their own questions (Hake, 1992, p. 546)

Overview

Chapter Two provides a review of the literature showing the problems in the field of instruction regarding motion and force and possible solutions to the problems. Procedures used to form the project are described in Chapter Three. In Chapter Four several activities are presented that can be used to augment a teacher's instruction on motion and force. Chapter Five contains my conclusions and recommendations on reference to this project. I include an appendix to show how these activities may be used in a unit.

Chapter II

Review of Literature

Introduction

In the preface to *Physics by Inquiry : Volume 1* McDermott (1996) states, "The process of science cannot be learned by reading, listening, memorizing, or problem-solving. Effective learning requires active mental engagement" (p. iii). The American Association for the Advancement of Science (1993) points out that, "Newton's laws of motion are simple to state, and sometimes teachers mistake the ability of students to recite the three laws correctly as evidence that they understand them" (p. 87). To avoid this mistake McDermott (1996) suggests, "Starting from their own observations, students develop basic physical concepts, use and interpret different forms of scientific representations, and construct explanatory models with predictive capability" (p. iii). Furthermore, the students need to be given situations that challenge their current beliefs (Gang, 1993; McDermott, 1991). The way physicist view motion may not be intuitive or common sense to many students and this may hinder their ability to learn new concepts (Halloun & Hestenes, 1985). Most common sense beliefs are formed by personal observations and were held by humans throughout history. Only with the advent of modern science were they challenged and revised because they fell short in explaining why objects move and the path objects take (Arons, 1990; Roach, 1992). Adding to the problem, science uses words in precise ways and they are the same words used by people everyday but in a different context

(Arons, 1990; Williams, 1999). The idea that students construct their own framework of knowledge for concepts may offer the solution to teaching if instruction is tailored to helping students build this framework (Arons, 1990; Fischer & von Aufschnaiter, 1993; Gang, 1993; Hake, 1992; Hestenes, 1992; McDermott, 1991; Van Heuvelen, 1991)

Common Sense and Instruction.

Robin Woods (1994) notes," That is, students enter school with a plethora of experiences, use this foundation to form personal theories (often erroneous) about the world, and rarely correct misconceptions even when new information is presented to them" (p. 33). A major problem then in teaching students the basic concepts of motion and force is that they already have internal concepts from experience with the world. According to Bauman (1992), "Newtonian physics is basically simple, but not always intuitive" (p. 407).

After testing middle school children in China, Gang (1993) concluded, "Students who hold P/AC [Preconceptions / alternative conceptions] either do not comprehend or else they misinterpret new information when it is organized according to the scientific concepts" (p.416). He also found that many of the teachers didn't consider these preconceptions important and that their positive examples would overcome them (Gang, 1993).

In an investigation of their students Trowbridge & McDermott (1980) found, "Students bring to the formal study of physics an intuitive sense of the meaning of common concepts associated with motion. Ideas of location, distance time, duration, speed, and acceleration exist as somewhat vague and undifferentiated notions" (p.1021). By using interview type questions, they found that many students use the language of physics and the concepts of physics but don't have a clear idea of how these connect to physical situations. They also can't make the connection between the formal presentation and their previously held beliefs (Trowbridge & McDermott, 1980).

Heller and Finley (1992) speak of "hard-core ideas" and "protective-belt ideas." That is learners in general have a central core of ideas that they are unwilling to change and another set of ideas that are held less strongly. The learners "adjust their protective-belt propositions to account for previously learned facts that contradict the predictions of their hard-core conceptions … ." (Heller & Finley, 1992, p.272). This behavior was also noted in students by other educators (Arons, 1990; Evans, 1978; Gang, 1993; Shepardson & Moje, 1994; Woods, 1994).

Otero and Graesser (2001) note that, "Readers are known to somehow miss many discrepancies between their world knowledge and text statements. They sometimes 'fix them up' in unacceptable ways instead of asking questions or identifying the discrepancy as a problem" (p.157). Thus, students rather than challenge their own ideas may just interpret what is taught in a way that fits with what they already think (Fleer, 1994; Osborne & Wittrock, 1983).

Much of the problem centers around what Arons (1990) describes as, "two principal classes of knowledge: figurative (or declarative) and operative (or procedural). Declarative knowledge consists of knowing facts. Operative knowledge, on the other hand, involves understanding the source of such declarative knowledge"(p. 290).

Halloun and Hestenes (1985) found that many of their students could quote ideas of motion but couldn't apply them. Many times a student's ability to manipulate formulas hide their understanding of the underlying principles that led to those formulas (Clement, 1982). This points to a difference between science teachers' perspective and that of their students (McDermott, 1991).

As Reif (1995) points out,

> For example, many students view science as a valuable collection of facts and formulas and thus pursue the goal of memorizing these. On the other hand, most physicists view science as a small body of basic knowledge enabling wide-ranging inferences about observable phenomena. When physicists try to teach reasoning abilities needed to make scientific inferences, they pursue then a learning goal different from that envisaged by the students. (p. 31)

To summarize a study, using a pretest and a posttest on their students, Hestenes, Wells, and Swackhamer (1992) state, "(1) commonsense beliefs about motion and force are incompatible with Newtonian concepts in most respects, (2) conventional physics instructions produces little change in these beliefs, and (3) this result is independent of the instructor and the mode of instruction"(p. 141). Common sense solutions can't be dismissed as misconceptions but must be shown invalid in some situations so students will look for more complete explanations of what they observe. As Halloun and Hestenes (1985) point out, "Indeed, physics and science in general can be regarded as an extension and modification of common sense"(p.1).

Hestenes, Wells, Swackhamer (1992) have divided these common-sense beliefs into the following six categories: (a) Kinematics involving the basic definitions of motion, position, velocity, and acceleration. (b) Impetus that refers to ideas held that if an object is moving there must be an intrinsic force keeping it going. (c) Active force that sees all motion as the result of an active force constantly pushing on the object. (d) Action and reaction forces are seen as battling each other with the strongest force winning and moving the object. (e) Concatenation of influences where students have trouble identifying the forces on an object and how they interact. (f) Students invent fictitious forces and have trouble identifying passive forces.

The idea is to present conflicts of thought in these areas and then guide the students into constructing the "Newtonian World" for themselves (Clement, 1982; Hestenes, 1992).

A Historical Perspective.

These conceptual problems should be seen in the context of history. The common sense ideas held by most students are the same ones encountered by "intellectual giants from Aristotle to Galileo"(Halloun & Hestenes, 1985). Only by testing these assumptions in experimental situations using the scientific method did current ideas prove valid and other hypotheses prove to fall short. Teachers must realize Galileo, Descartes, and Newton didn't come to ideas of kinematics and dynamics in some flash of brilliance and chances are neither will their students (Arons, 1990; Roach, 1992). The American Association for the Advancement of Science (1993) adds, "The fact that it took such a long time, historically, to codify the laws of motion suggests that they are not self-evident truths, no matter how obvious they may seem to us *once we understand them well*." (p. 87)

Problems with Language.

One of the major problems students have with concepts in physics is the language used to describe the rules and situations. For the most part the words are from everyday language but are given very specific meanings (Williams, 1999). As Arons (1990) puts it,

> Many presentations start in by ignoring the fact that the words "force" and "mass," which, in every day speech, are heavily loaded metaphors, are being taken out of everyday context and given very sophisticated technical meaning, completely unfamiliar to the learner. (It is even implied, in some presentations, that the student already knows the scientific meaning of the terms.) Students have, in general, not been made self-conscious about, or sensitive to, such semantic shifts, and they continue to endow the terms with the diffuse metaphorical meanings previously absorbed or encountered. It is helpful to make students explicitly conscious of the fact that the words remain the same but that the meanings are to be sharply revised. (p. 50)

To add to this problem textbooks as well as teachers are not careful how they use words even if the technical definitions are given. This compounds the confusion that students may already be experiencing as they try to learn concepts and definitions of physics. The following problems were found in a survey of five introductory text books: (1) everyday words used with a specific technical definition, (2) technical words or phrases defined differently by different authors, and (3) principles or concepts defined imprecisely (Williams, 1992). This language problem causes trouble before students even begin to wrestle with applying concepts to explain situations presented to them.

Relationship of Motion and Force.

Any discussion of motion leads to Newton's Laws that deal with the interaction of forces that produce motion. Most researchers have found that students have what is called "motion implies a force" belief. That is if there is a motion a force must be involved. This leads to several inconsistencies when explaining certain kinds of motion. Including the invention of forces, forces increasing or decreasing for no reason, and inertia seen as a force (Arons, 1990; Clement, 1982; Halloun & Hestenes, 1985; Hestenes, Wells, Swackhammer, 1992). As Clement (1982) point out,

> The "motion implies a force" preconception is not likely to disappear simply because students have been exposed to the standard view in their physics courses. More likely, Newtonian ideas are simply misperceived or distorted by students so as to fit their existing preconceptions; or they may be memorized separately as formulas with little or no connection to fundamental qualitative concepts. (p. 70)

Another problem is identified by Boyle and Maloney (1991), "These ideas imply an ultimate conception of a force as either a thing in itself, a property of an object, or an event" (p.137). The knowledge being imparted is disconnected from what is actually learned. Several researchers believe this may be attributed to prior knowledge of the students (Arons, 1990; Boyle & Maloney, 1991; Clement, 1982; Reif, 1995).

Constructivism

As expressed by Boyle & Maloney (1991),

> One possible explanation for the subjects' rejection of the given information emerges if we adopt the viewpoint that people construct knowledge and that the construction process operates with the knowledge base the individual already possesses. (In talking about the knowledge the individual already possesses it is irrelevant whether that knowledge is correct or incorrect as judged on the basis of some objective criteria.) One such "constructivist" perspective includes the process of encoding. In this model encoding involves monitoring, i.e., identifying the new information, and construction of new knowledge in memory. This new knowledge is a result of the translation of the new information using the already present knowledge as the basis of the translation. The combination process involves three sub-processes: deciding which features of the situation to include, deciding how to organize these into a rule, and execution of the chosen rule. (p. 138)

To this view of constructivism McDermott (1991) adds,

> In non-technical terms, we can briefly summarize the constructivist view of how scientific knowledge is acquired as follows: All individuals must construct their own concepts, and the knowledge they already have (or think they have) significantly affects what they can learn. The student is not viewed as a passive recipient of knowledge but rather as an active participant in its creation. Meaningful learning, which connotes the ability to interpret and use knowledge in situations not identical to those in which it was initially acquired, requires deep mental engagement by the learner. The student mind is not a blank slate on which new information can be written without regard to what is already there. If the instructor does not make a conscious effort to guide the student into making the modifications needed to incorporate new information correctly, the student may do the rearranging. In that case, the message inscribed on the slate may not be the one the instructor intended to deliver. (p. 305)

If constructivist theory is true, the student may not be able to encode the new information because it is in conflict with previous knowledge (Boyle & Maloney, 1991). Gang (1993) suggests, "Learning cannot take place and the students' P/AC cannot be replaced by scientific concepts. We must first shake and discredit such organizing and interpretative roles of the students' P/AC so that they will reconsider the justifications for holding the P/AC and begin to pay attention to the new information" (p. 416, 417).

The challenge then is to provide students with enough guidance yet freedom to develop the ideas of motion (McDermott, 1991). As DePosa (1997) concluded," Instead, students need to integrate new, scientific knowledge with their alternative conception through a complex process of conceptual change. Students modify or restructure their previous knowledge, or completely abandon it, and accept new knowledge that seems counterintuitive" (p. 446).

Possible Solutions

Constructivism and the Socratic Method. The examination of student performance and the constructivist interpretation provide some hints to possible solutions to the dilemma in physics education. In constructivst theory knowledge is constructed not discovered. Historically this can be seen if one examines the thoughts of scientists like Galileo and Newton. In their early writing, both embraced some of the ideas that students have when they enter science courses. This implies that understanding motion is a creative act that requires active engagement (Arons, 1990; Hestenes, 1992; Fischer & von Aufschnaiter, 1993; McDermott, 1991). Clement (1982) defines two goals of constructivist pedagogy in science education,

> In this approach to attacking the problem, the goal is to find teaching strategies that encourage students to articulate and become conscious of their own preconceptions by making predictions based on them. A second goal is then to encourage them to make explicit comparisons between these preconceptions, accepted scientific explanations, and convincing empirical observations. (p. 70)

Clement (1982) points to the "Father of modern science" Galileo, as an example of where to start solving the problems of physics instruction. He points out that Galileo in his work, *Two New Sciences*, uses a dialog to discus motion (p. 70). Hake (1992) expands this idea to what he calls the "Socratic Dialogue" (p. 546). Hestenes (1992) explains major strengths and weaknesses of the Socratic method,

> (1) It shifts the *focus of control* from teacher to student, making students responsible for their own beliefs and judgements. It is student centered rather than teacher centered. (2) It *encourages reflective thinking*, leading students to insights into their own thinking processes. In short, it promotes intellectual independence. The pure Socratic method, however, has serious weaknesses: It is not systematically directed at specific objectives, and it lacks a mechanism for introducing new ideas and conceptual tools to improve the quality of the discourse. (p. 747)

Qualitative Method. In the qualitative method the instructor introduces the ideas and guides the questions. The students then develop models to explain physical situations. From these models they make predictions and test the validity of the model (Hake, 1992; Hestenes, 1992). A major component of this method is student recognition of patterns and how they apply from situation to situation (Hestenes, 1992).

This implies that teaching recognition skills is another important aspect of physics instruction. Students will have to learn these skills on simple concepts before they can be applied to the less obvious patterns used to demonstrate motion. The use of qualitative rather than quantitative problems becomes an important tool in developing these strategies. That is students need to get a grasp of the physical situation by drawing pictures and diagrams to understand problems. Then describe in words their reasoning before they throw numbers at formulas. Most students don't have these skills (Van Heuvelen, 1991). Reif (1995) explains what is needed in physics instruction, " teach explicitly the prerequisite knowledge required for description and interpretation, ... embed quantitative treatments in qualitative frameworks, ... solving qualitative as well as quantitative problems, ... qualitative checks and dependencies [on quantitative solutions]" (p. 23). Physics courses then must incorporate pictures, diagrams, words as well as formulas to give students the ability to build their own knowledge. The students then must be given sufficient practice and guidance to develop the skills and knowledge for themselves. Several methods have been developed using paper and pencil handouts, laboratory exercises, or computer exercises. The methods can be found in the wide range of the literature written about science and the classroom. Several of these have been used individually or in combination by the authors used in this paper. Much of the curriculum that has been developed from these methods include small group discussions and class discussion to get students to examine their own thought processes (Hake, 1992; Heller, Keith, & Anderson, 1992; Hestenes, 1992; McDermott, 1996; Van Heuvelen, 1991).

Most of the methods use a form of the following outline as developed by Heller, Keith, and Anderson (1992) to solve problems.

1. Visualize the problem
    - draw a sketch of the situation;
    - identify the known and unknown quantities and constraints;
    - restate the question;
    - Identify a general approach to the problem – what physic concepts and principles are appropriate to the situation.
2. Describe the problem in physics terms ...
    - use identified principles to construct idealized diagrams ...
    - symbolically specify the relevant known and unknown variables
3. Plan a solution
    - Translate the physics description into a mathematical representation of the problem:
    - start with identified physics concepts and principles in equation form ...
    - apply the principles systematically ...
4. Execute the plan

    Translate the plan into a series of appropriate mathematical actions. ...
5. Check and evaluate

    Determine if the answer makes sense. (p. 630)

Conclusion

Problems in teaching motion stem from students' own prior knowledge of how the world works. These preconceptions are well rooted in the history of humankind. Strategies then must be developed to help students encounter conflicts between observation and their views. They then must be given the tools to resolve those conflicts and create a new set of explanations in their own minds. Newton's laws can't be taught in an intellectual void, but must be a part of an overall strategy to equip students with the ability to acquire knowledge that may be counter to their own intuition. Osborne and Wittrock (1983) point out,

> In terms of the model, learning science is a disciplined creative process. Even when a teacher gives a pupil an explanation for how and why something behaves as it does, the pupil must still actively create meaning from that explanation. Teaching involves helping pupils to generate appropriate meanings from incoming information, to link these meanings to other ideas in memory and to evaluate both newly constructed idea and the way old ideas are related in memory. In addition, the successful learning of scientists' ideas is as much a restructuring of the way learners think about the world as it is the accretion of new ideas to existing ways of thinking. (p.505)

Rosalind Driver states, "Its not just a matter of having just hands-on experience in science. It's important to have heads-on experience as well. Learners must think things through and reconstruct their interpretation of things" (Schneps, 1997).

Chapter III

Procedures of the Project

Introduction

This project was developed to help Middle School and High School Science Teachers with resources for the current scientific view of motion. Each activity in Chapter Four is designed as a supplement to current instruction. The idea is to not only give examples of how motion is viewed but also provide questions that may get the students to refine their thinking to better see why scientist believe what they do about motion.

This project has its roots in my own struggles to understand Newton's Laws of Motion. As I struggled to apply the concepts in college, I found I had difficulty asking the right questions while exploring situations and problems presented in the textbook. Unfortunately, the only way the material was presented was in lecture format. As I taught, my students were having the same problems and adding "hands-on" inquiries didn't seem to help much. The students still weren't able to ask themselves leading questions.

Procedures

After discovering students have the same problems with the concepts of motion as I did, I talked to my colleagues about my concerns. While they had made similar observations they had few ideas. In February of 2002 I attended a workshop on teaching Physical Science by Al Guenther. This workshop covered many topics and it helped me begin to develop relevant questions that pertain to physics exercises the students participate in doing. Mr. Guenther drove home the point that students must be actively interacting with activities not just doing them. He emphasized asking questions that lead to deeper thinking. Looking for what is happening not just collecting numbers to be thrown into formulas.

This led me to examine the literature on the subject of science education. This search was done using the education resources information center (ERIC), several periodical search engines on the Internet, and the *Physics InfoMall* CD (The Learning Team, 1995) which contains selected publications on physics. Key terms used in the search were “motion,” “Newton’s Laws,” “science education,” “hands on inquiry,” and “inertia.” I also acquired textbooks and other materials that have been produced on the subject of science education especially in physics.

The literature was rich with ideas concerning why students don't learn science very well. Some authors offered solutions. As noted in chapter one, the author identified two major problems with the literature. First the audience of the articles and second few concrete examples were provided. Most of the information was focused on college courses (Hake, 1992; Hestenes, 1992; McDermott, 1996; Reif,1995; Van Heuvelen, 1991). Most of the information and collections of activities only focused on procedures. Few examine or give examples of questioning that stimulate inquiry. Mr. Guenther (2001) includes only one example of how to conduct guided questions and this was done at the broader class level not with individual students.

Having taught motion as part of a Ninth-grade Science class with often disappointing results, I saw a need to develop a curriculum that included guided questioning for individuals or small groups. Included in the appendix is a curriculum the author developed using some of the activities included in this project but without the questioning. The students doubled their pretest scores on the posttest but they still answered less than half the questions correctly. So I went through the literature, looked at activities I already use, and asked my colleagues for suggestions. Guiding questions were then written and added to the activities using guidelines from the American Association for the Advancement of Science (AAAS, 1993), and the National Science Education Standards (NAS, 1996).

The questions and activities were aligned with the Washington State Essential Academic Learning Requirements (WSCSL, 1998). These were then assembled as a handbook to supplement instruction.

This body of work is not meant to be an end but a beginning. The questions are designed to stimulate inquiry not end it. It is hoped that students will be able to use these questions to develop thought patterns that can be used to solve problems. To this end extended exercises have been included in the handbook. These extended exercises don't have guided questions but give the students the opportunity to apply their knowledge to solve problems.

Chapter IV

Project

Overview

The following project includes activities that can be used to supplement units on motion and force. Each activity includes an objective, the materials needed, a description of the procedure, data collection, and guiding questions. Essential Academic Learning Requirements for the State of Washington are included for each of the activities. These activities are not designed to be a curriculum, therefore, they are not put in order of use and each user needs to determine where they fit in the individual instruction. They have been broadly arranged as demonstrations, inquiries, and projects. The goal was to create activities that stimulate further inquiry.

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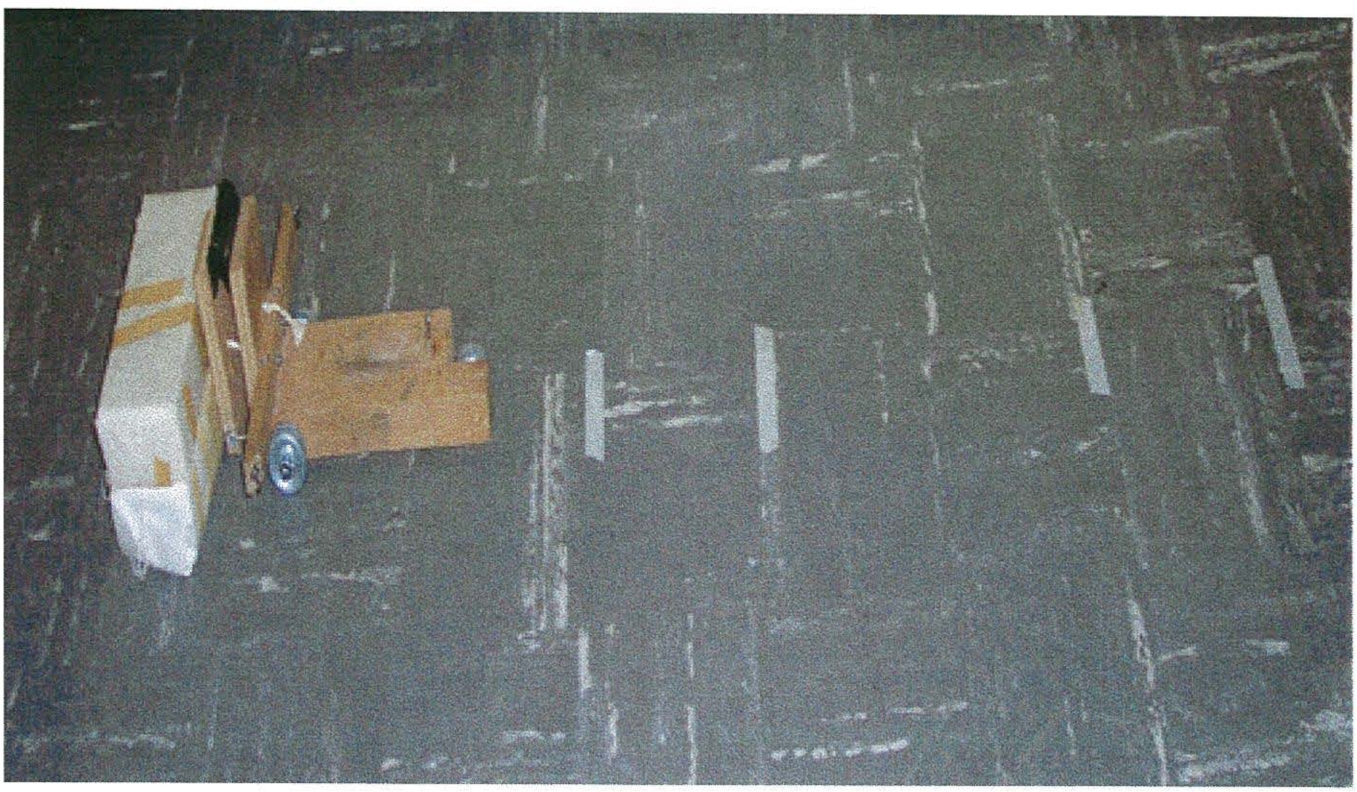
Speed with Carts



Speed with Carts

Objective:

Students will relate distance, time and speed.
Students will use change in speed over time to find acceleration.

EALR:

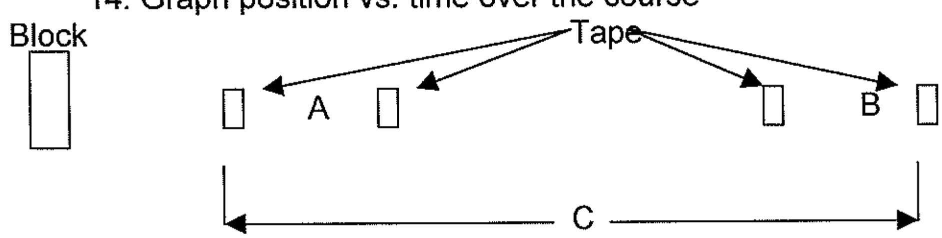
1.1 Describe the positions, relative speeds, and changes in speed of objects.
2.1 Formulate and revise scientific explanations and models using logic and evidence; recognize and analyze alternate explanations and predictions.
2.1 Study and analyze questions and related concepts that guide scientific investigations.
2.1 Use mathematics, computers, and/or related technology to model the behavior of objects, events, or processes.

Materials:

A cart with some launching mechanism such as a Pasco Dynamics Cart
Meter stick 3 stopwatches Tape Heavy block

Procedure:

1. Place the block on the floor.
2. About 50 cm from the block place a piece of tape to mark the origin.
3. Place another piece of tape 50 cm from the first. This is space A.
4. 1 meter from the second piece of tape place a third piece of tape on the floor.
5. 50 cm from the third piece of tape place a fourth piece of tape. The space between the third and fourth pieces of tape is space B.
6. The distance of 200 cm from the first piece of tape and the fourth piece of tape is space C.
7. Place the cart against the block and launch it down the track.
8. Time space A with one watch, Space B with another watch, and space C with the third watch.
9. Record in table.
10. Repeat steps 7 - 9 five times.
11. Average the times and record.
12. Find the speed for space A, space B, and space C.
13. Find the acceleration by using the difference in speed between A and B and time C.
14. Graph position vs. time over the course



Data:

Run	Time A (s)	Time B (s)	Time C (s)
1			
2			
3			
4			
5			
Average			
Speed	cm/s	cm/s	cm/s

Acceleration ____________________ cm/s^2

Analysis:

1. Are the changes in position different from A to B. That is, the distance between the 1st tape and the last tape in set A the same as in set B?

2. How does the time through A compare with the time through B?

3. How does the velocity through A compare with velocity through B?

4. How does time relate to speed that is if time increases when change in distance is constant what happens to speed?

This is called an inverse relationship, which can be seen in the formula for velocity.

5. From the formula velocity = displacement / time what happens to velocity as distance increases?

6. From the formula what happens to velocity as time increases?

Look at the change in velocity from A and B.

7. Over what amount of time did this change take place?

8. If the displacement A and B are the same, does the change in velocity relate to the displacement of A or B?

This is a change in velocity over a clock reading not a change in position and is called acceleration.
Look at the position vs. time graph.

9. What is the slope of the graph from t = 0 until the 1st tape?

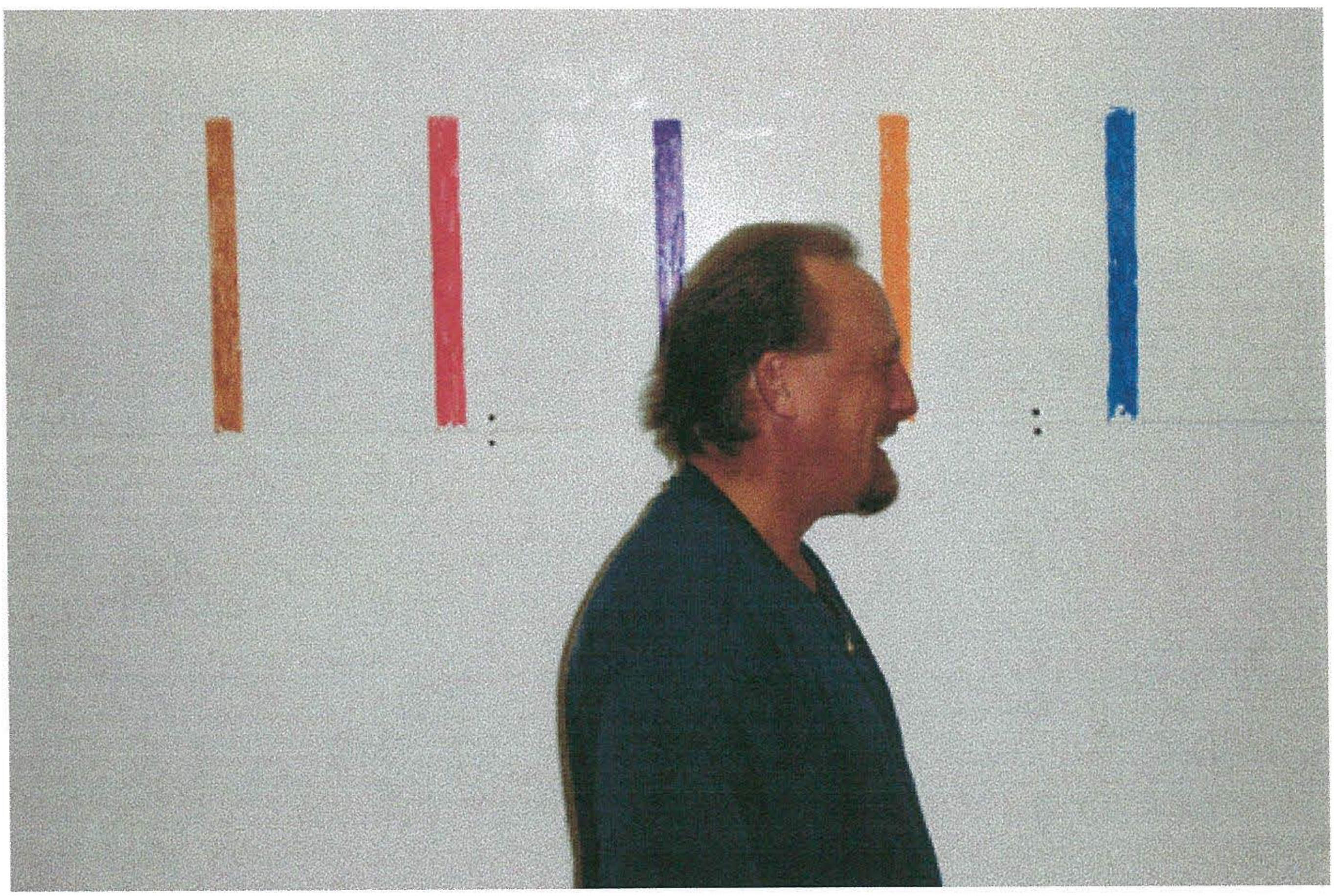
10. How does this compare to Speed A?

11. What is the slope of the graph from the time of the 3rd tape to the end?

12. How does this compare to Speed B?

13. How does the slope during the 1st section of the graph and the last section of the graph compare?

Speed and Acceleration with a Video



Speed and Acceleration with a Video

Objectives:

The students will determine speed using a video camera.
The students will demonstrate constant speed.
The students will demonstrate acceleration.

EALR:

1.1 Describe the positions, relative speeds, and changes in speed of objects.
1.1 Describe the average speed, direction of motion, and average acceleration of objects; for example: increasing, decreasing, or constant acceleration.
2.1 Use evidence from scientific investigations to think critically and logically to develop descriptions, explanations, and predictions.
2.1 Use mathematics, computers, and/or related technology to model the behavior of objects, events, or processes.
2.1 Research, interpret, and defend scientific investigations, conclusions, or arguments; use data, logic, and analytic thinking as investigative tools; express ideas through oral, written, and mathematical expression.

Materials:

Video camera   Strips of paper 1" wide and 1.5' long

Procedure:

Make a 3m background for the video by placing the strips of paper on the wall at 25-cm intervals.

Part 1

1. Walk in front of the background at a constant rate of speed while you are being taped.
2. By counting the number of frames it takes to move 3 meters you can determine your speed. Each frame is one-thirtieth of a second.
3. Record the result.

Part 2

1. Walk in front of the background to demonstrate acceleration.
2. By analyzing the tape frame-by-frame you can tell approximately how fast you were going at the beginning and how fast you were going at the end. Calculate and record those speeds.
3. Calculate the total time you took to walk 3 meters.
4. Use your change in speed and time to calculate your acceleration. Record.

Data:

Part 1

Speed ______________m/s

Part 2

Speed at the beginning ______________ m/s

Speed at the end ______________ m/s

Acceleration ______________m/s^2

Analysis:

1. Does the tape show that you maintained a constant speed?

2. Does the tape actually show that you changed speed in Part 2? If not how should you change the way you walked?

Frames of Reference
Skateboarders

Frame of Reference
Timing as Skateboarders Pass

Objectives:

The students will observe the same motion from two different frames of reference.

The students will demonstrate an understanding that the same motion may appear different from different frames of references.

EALR:

1.1 Describe the positions, relative speeds, and changes in speed of objects.

1.1 Describe the average speed, direction of motion, and average acceleration of objects; for example: increasing, decreasing, or constant acceleration.

2.1 Use evidence from scientific investigations to think critically and logically to develop descriptions, explanations, and predictions.

2.1 Formulate and revise scientific explanations and models using logic and evidence; recognize and analyze alternate explanations and predictions.

2.1 Research, interpret, and defend scientific investigations, conclusions, or arguments; use data, logic, and analytic thinking as investigative tools; express ideas through oral, written, and mathematical expression.

3.1 Identify and evaluate factors that limit the extent of a scientific investigation.

Materials:

2- Skateboards or low friction carts the same length

4- Stopwatches

Procedures:

(Note: Have the students practice making the runs with skateboards, then make five timed runs.)

1. Have the students perform the following situations.
2. For each situation four times will be taken, all times are measured from when the front of the boards passes the point to when the back of the board passes the point.
    a. Skateboarder A by someone is standing on the ground.
    b. Skateboarder B by someone is standing on the ground.
    c. Skateboarder A as seen by Skateboarder B.
    d. Skateboarder B as seen by Skateboarder A.
3. Record the times.

(Note: Follow safe procedures, the observations are easier at slower speeds.)

Situation 1:

Both skateboarders going the same speed shoulder to shoulder in the same direction past a point.

Situation 2:

Both skateboarders going the same direction but one is faster than the other. If possible time their ground frame of reference as they pass each other.

Situation 3:

The skateboarders are going in the opposite direction. Again time the ground frame of reference as they are passing.

Data:

Situation 1:

A to ground	B to Ground	A to B	B to A

Situation 2:

A to ground	B to Ground	A to B	B to A

Situation 3:

A to ground	B to Ground	A to B	B to A

Analysis:
(Note: Because the runs were not all the same speed look for trends not the same numbers each run.)

1. In situation 1, how did the times for A as viewed by a stationary observer on the ground compare to times for B as viewed by a stationary observer the ground?

2. In situation 1, how did time A to B compare to B to A?

3. In situation 1, how did times A to B and B to A compare to times A to ground and B to ground?

4. In situation 2, how did the times for A to the ground compare to times for B to the ground?

5. In situation 2, how did time A to B compare to B to A?

6. In situation 2, how did times A to B and B to A compare to times A to ground and B to ground?

7. In situation 3, how did the times for A to the ground compare to times for B to the ground?

8. In situation 3, how did time A to B compare to B to A?

9. In situation 3, how did times A to B and B to A compare to times A to ground and B to ground?

10. If the same action was being viewed, skateboarders riding past a point, why were the times longer for the skateboards compares to observers on the ground in situation 1 and 2?

11. Why were the times shorter for the skateboarders compared to the observed on the ground in situation 3?

12. Use speed = distance / time to find the speeds of the skateboarders from one run of each situation.

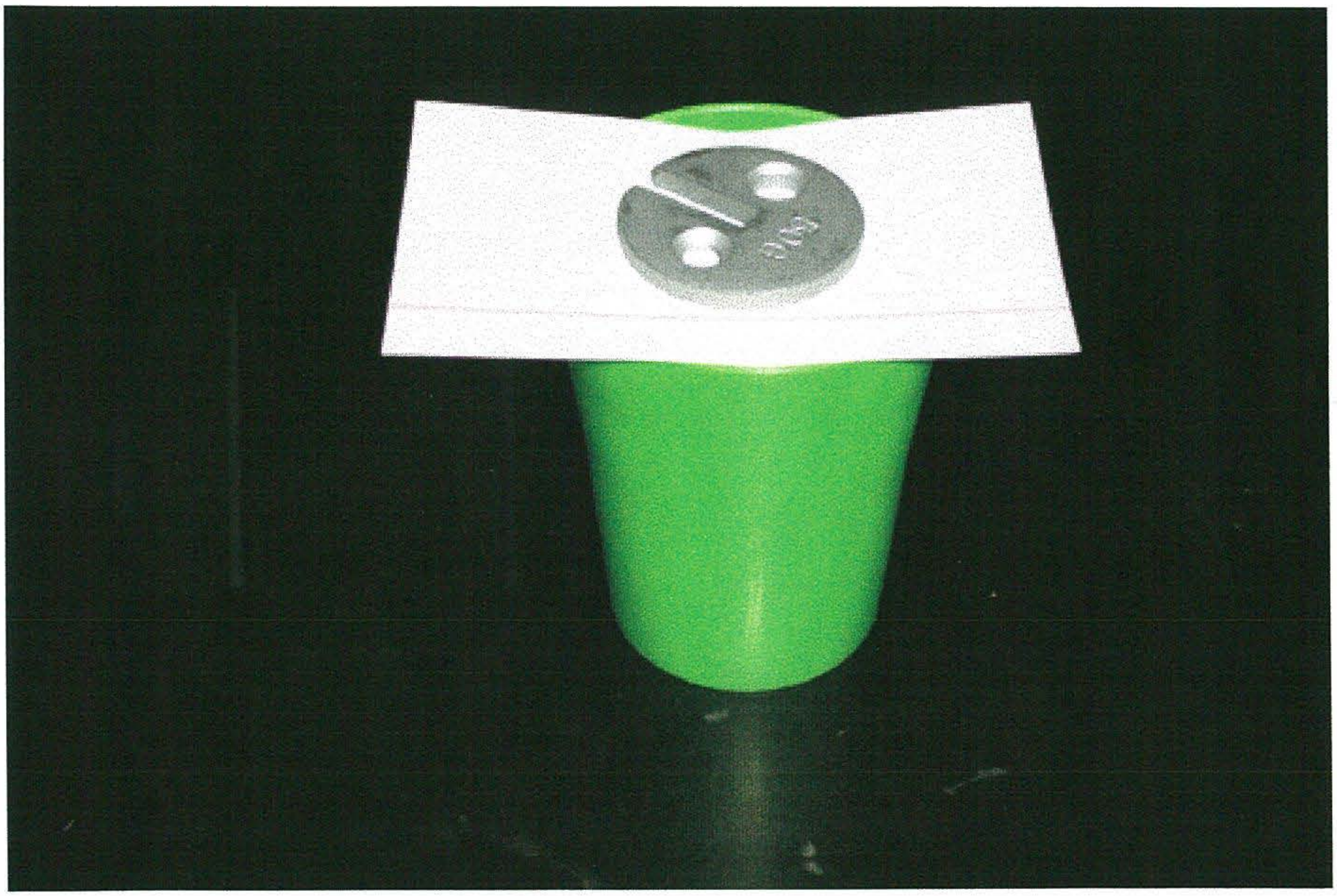
	A to Ground	B to Ground	A to B	B to A
Situation 1				
Situation 2				
Situation 3				

13. Compare the speed relative to the ground to the speeds relative to the skateboarder.

14. In what ways are the speed comparisons similar to the time comparisons and in what ways do they differ?

15. How does frame of reference affect the observer's perceptions of speed?

Card and the Coin



Card and Coin

Objective:

The students will explore force, motion, and impulse.
The students will develop an explanation for their observations.
The students will revise their explanations if necessary with further observations.

EALR:

1.3 Identify various forces and their relative magnitudes and explain everyday situations in terms of force.
2.1 Use evidence from scientific investigations to think critically and logically to develop descriptions, explanations, and predictions.
2.1 Formulate and revise scientific explanations and models using logic and evidence; recognize and analyze alternate explanations and predictions.
2.1 Research, interpret, and defend scientific investigations, conclusions, or arguments; use data, logic, and analytic thinking as investigative tools; express ideas through oral, written, and mathematical expression.

Materials:

Coin   3 X 5 filing card   Water glass   Various other objects

Cards made of various materials like sandpaper, thin paper, or playing cards

Procedure:

1. Teacher demonstrates by placing the card on the water glass and setting the coin on the card. 2. Give the card a quick flick or quick pull. 3. The students are given the materials and begin to try the same inquiry with various cards and objects.

Data:

Demo: Teacher flicks a card from under a penny.

Describe what happens.

Make a hypothesis as to why it happens.

Explore:

Try the trick yourself

Try removing the card slowly

What happened?

Give a possible explanation of the reaction.

Try the different cards.

Describe what happens and explain the reactions

Try different objects on top of the cards

Describe what happens and explain the reactions

Analysis:

1. Did changing the surface make it harder to perform the trick?

2. Were there any objects that didn't work for performing the trick?

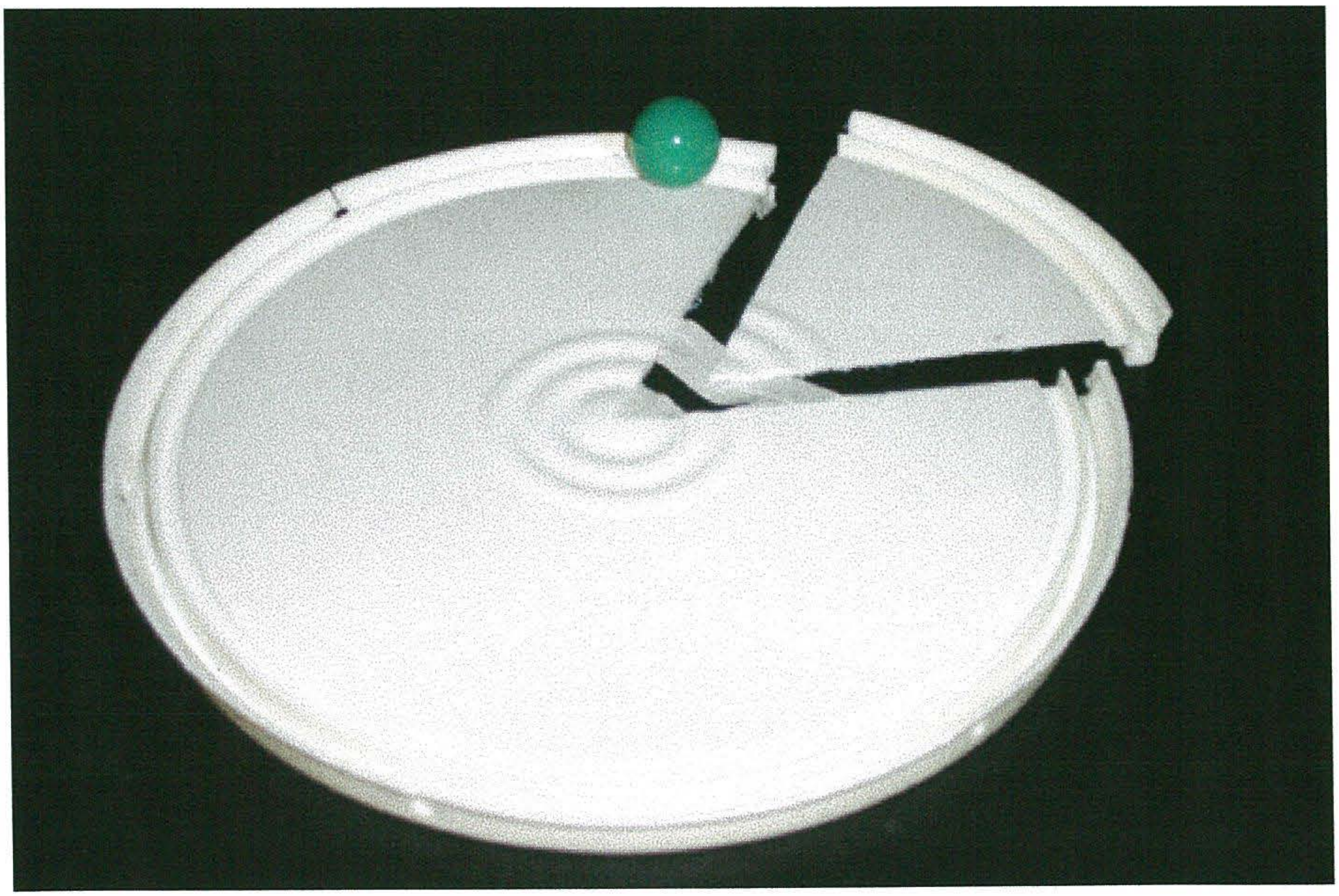
3. What was the one thing that was necessary to make the object fall in the cup?

4. Why do you think moving the card slowly caused the object to move while moving the card rapidly caused the object to fall?

5. Since you could still do the trick using sandpaper does friction seem to cause much difference?

6. Newton claimed that objects tend to stay in constant motion unless acted on by outside forces. Could this tendency be used to explain your observations? Explain.

Inertia and the Curve



Inertia and the Curve

Objectives:

The students will develop the idea of how inertia affects an object going around a curve.

EALR:

1.3 Explain the effects of unbalanced forces in changing the direction of the motion of objects.

2.1Use evidence from scientific investigations to think critically and logically to develop descriptions, explanations, and predictions.

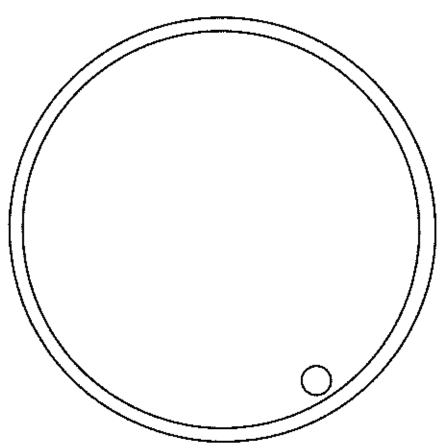
2.1 Formulate and revise scientific explanations and models using logic and evidence; recognize and analyze alternate explanations and predictions.

Materials:

Plastic plate Marble Scissors Tape

Procedure:

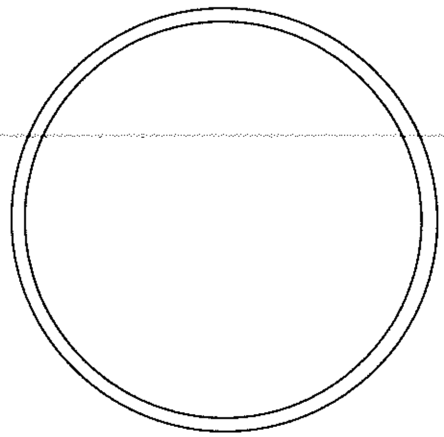
1. Roll the marble around the rim of the plate.
2. Note the path of the marble on the report sheet.
3. Cut a wedge out of the plate (about 1/4 of the plate)
4. Make a prediction as to the path the marble will take when it hits the gap in the plate.
5. Record this prediction on the report sheet.
6. Try rolling the marble around the plate.
7. Note the path of the marble on the report sheet.



Report for Inertia and the Curve

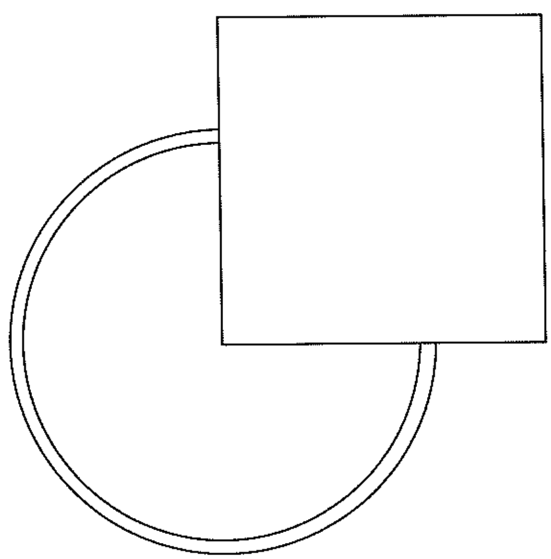
Data:

Sketch the path of the marble in the plate.



Predict the path the marble will take if you remove part of the plate.

Sketch your prediction inside the box using a solid line.



Sketch the path the marble actually took using a dashed line.

Analysis:

1. Did your prediction match the path the marble actually took?

2. When you first rolled the marble in the plate what kept the marble rolling in a circle?

3. What was the edge applying to the marble to make it follow the curved path?

4. What happened when the edge was removed? What path did the marble take?

5. If the edge is no longer present what was no longer being applied to the marble?

6. Once the edge was removed, removing the force, what path did the marble take?

7. Based on these observations, what seems to be the path of an object when no force is acting on it?

8. Was the speed of the marble changing much as it moved?

9. Primarily what was the force from the edge of the plate doing to the marble?

Newton's Skateboarder

Newton's Skateboarder

Objective:

The students will demonstrate the relationship between mass, force, and acceleration.

The students will develop Newton's Second Law equation.

EALR:

1.1 Describe the average speed, direction of motion, and average acceleration of objects; for example: increasing, decreasing, or constant acceleration.

1.3 Explain the effects of unbalanced forces in changing the direction of the motion of objects.

2.1 Use evidence from scientific investigations to think critically and logically to develop descriptions, explanations, and predictions.

Materials:

Skateboards   Bathroom scales

Procedure:

1. Select a starting point on a smooth, straight, level surface like a hallway.

2. One student sits on the skateboard while another student holds the scales on their back. A third student holds the first one from moving.

3. Zero the scale against the student's back.

4. Have the student holding the scale push with the desired force.

5. The student doing the pushing must maintain a constant force.

6. On signal the student doing the holding will let go.

7. Observe the speed of the person on the skateboard and record.

8. Repeat with larger forces.

9. Repeat the experiment using the medium force but people of different mass on the skateboard.

Data:

Use words to describe what you see.

Constant mass

Force (lbs.)	Acceleration
5	
10	
15	

Constant force

Mass	Acceleration
Small	
Medium	
Large	

Analysis:

1. Draw a diagram showing the forces on the skateboarder.

2. What happened to the speed of the skateboard in order to maintain a constant force in each case?

3. In most cases the speed increased while the force remained constant, what seems to be the relationship between force and acceleration?

4. How do you explain that at the 5 lbs of force the speed was constant?

5. How does this relate to the idea of net force?

6. From these observations, how must the force of the person pushing the scale be compared to the person keeping the skateboarder from moving at the start of the inquiry?

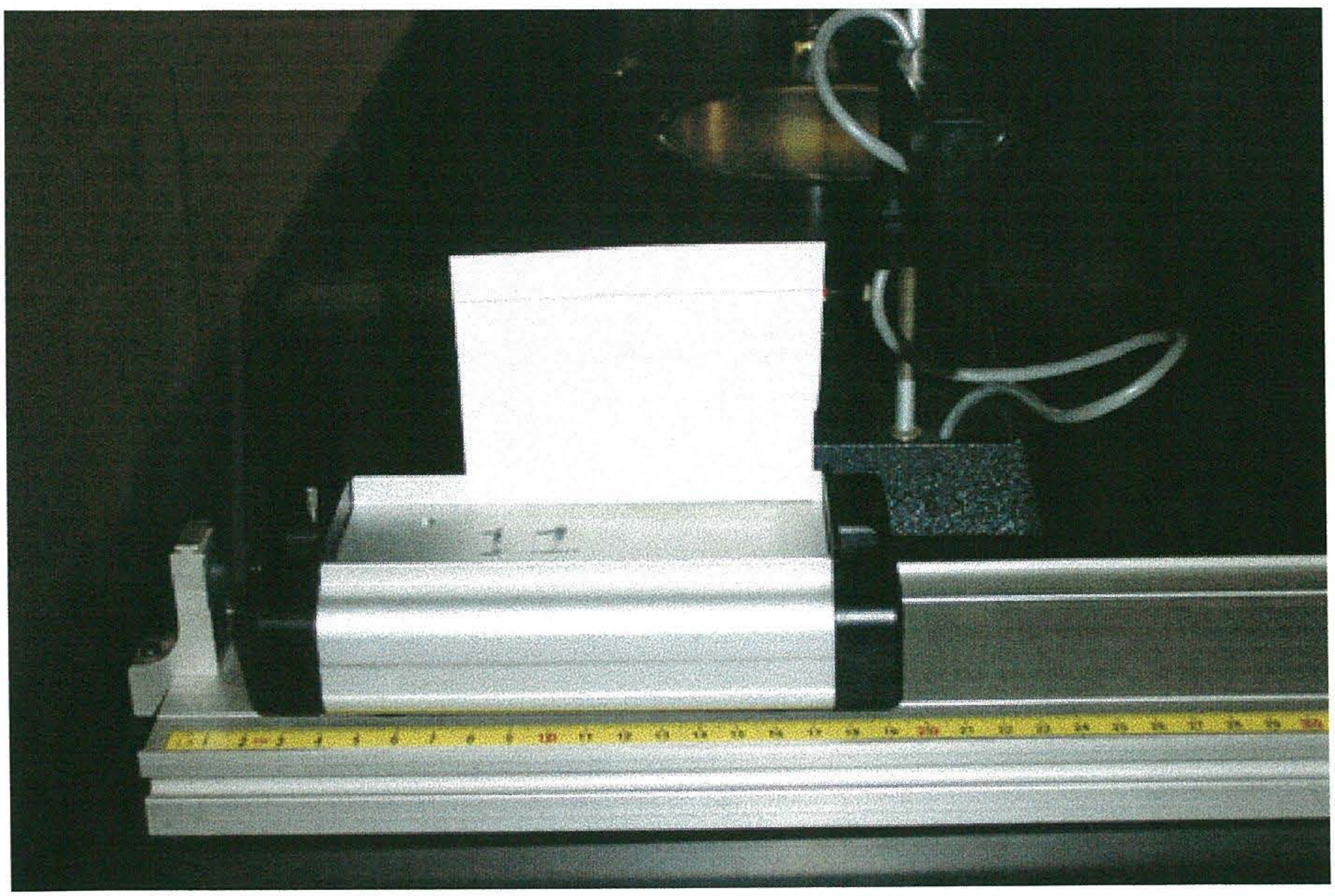
7. How did the increase in mass affect the increase in speed?

8. Does your findings show the same trends as noted by Newton in his famous equation $F_{Net} = ma$?

9. Rewriting the formula as $a = F_{Net} / m$ what happens:
   a. To the acceleration as Force increases?

   b. To the acceleration as mass increases?

Newton's Second Law



Newton's Second Law

Objective:

The students will demonstrate the relationship between mass, force, and acceleration.

The students will develop Newton's Second Law equation.

EALR:

1.1 Describe the average speed, direction of motion, and average acceleration of objects; for example: increasing, decreasing, or constant acceleration.

1.3 Explain the effects of unbalanced forces in changing the direction of the motion of objects.

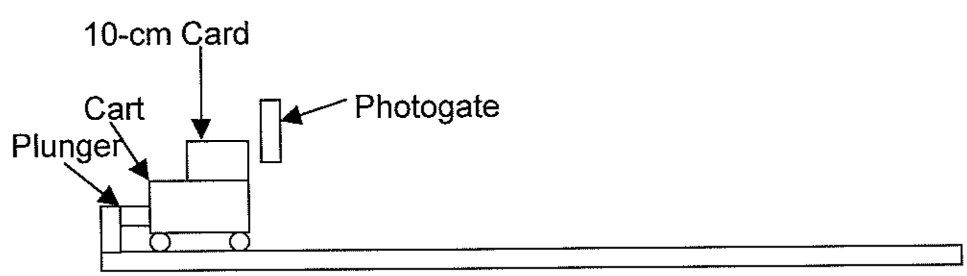
2.1 Use evidence from scientific investigations to think critically and logically to develop descriptions, explanations, and predictions.

Materials:

Dynamics cart   Track   Extra masses   Photogate timer

Procedure:

1) Attach a 10-cm card to the Dynamics cart.
2) Set the cart on the track while the plunger is fully extended against the stop at the end of the track.
3) Set the photogate timer so the photogate is just ahead of the card.
4) Depress the plunger one notch.
5) Place the cart on the track with the plunger against the stop.
6) Set the timer to record the time it takes for the card to pass through the gate.
7) Release the cart by striking the plunger release pin.
8) Record the time in the table.
9) Repeat steps 4 through 8 three times.
10) Average your results.
11) Find the velocity by dividing 10 by the average time.
12) Depress the plunger two notches and repeat steps 5 through 11.
13) Depress the plunger three notches and repeat steps 5 through 12.
14) Depress the plunger three notches, add a mass bar to the cart and repeat steps 5 through 11.
15) Depress the plunger three notches, add two mass bars to the cart and repeat steps 5 through 11.



Data:

Force	Time 1	Time 2	Time 3	Average Time	Velocity
1					
2					
3					

Mass of the cart = 500 g   Mass of one bar = 500 g

Mass	Time 1	Time 2	Time 3	Average Time	Velocity
500 g					
1000 g					
1500 g					

Analysis:

1. Draw a force diagram for the cart.

2. The cart is standing still at the beginning of this investigation, so we can say the change in velocity is equal to the final velocity. For the purpose here, we may assume the time for each push by the plunger is approximately the same and we can call this time equal to 1. The acceleration then becomes equal to the final velocity.

   a. Graph the acceleration on the Y-axis and the force on the X-axis. Is the slope of the graph positive or negative?

   b. Graph the acceleration on the Y-axis and the mass on the X-axis. Is the slope of the graph positive or negative?

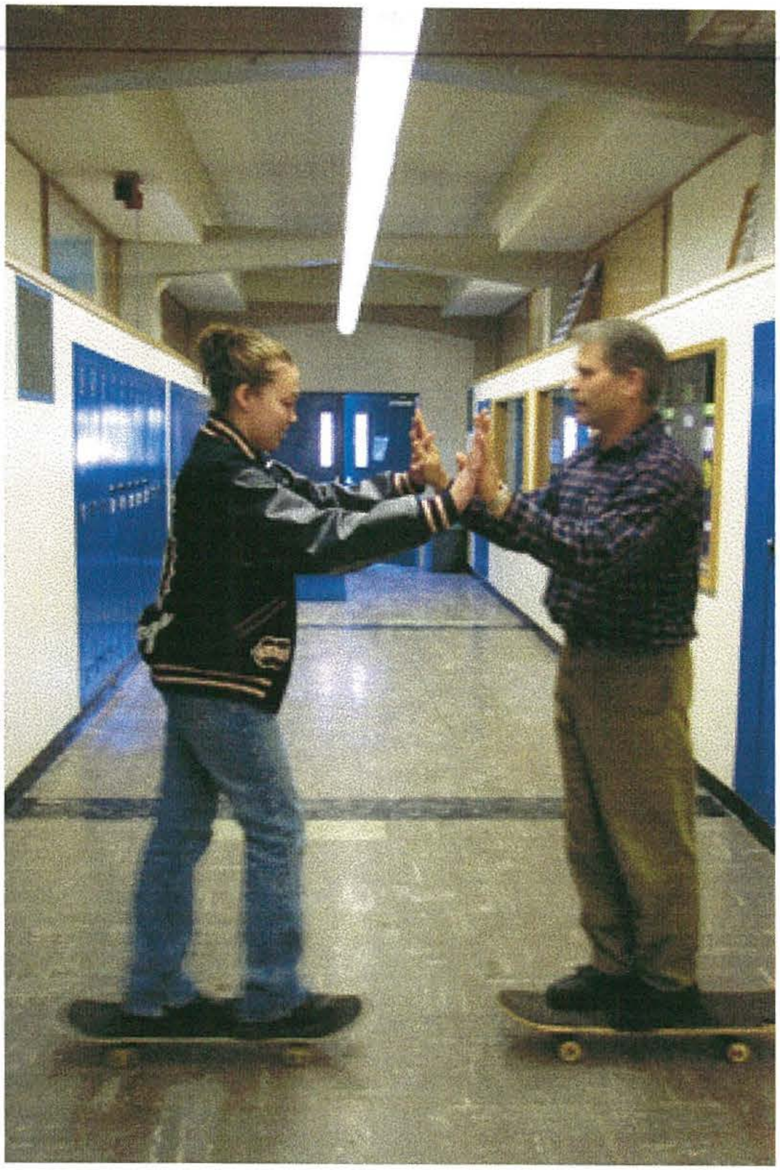
   c. Graph the acceleration on the Y-axis and the inverse of the mass on the X-axis. Is the slope of the graph positive or negative?

3. From the acceleration vs. force graph, how does the acceleration relate to force. That is if force increases what happens to the acceleration?

4. From the acceleration vs. mass and the acceleration vs. inverse mass graphs, how does the acceleration relate to the mass?

5. Write the relationship between acceleration, force, and mass as a single equation.

Newton's Third Law with Skateboards



Newton's Third Law with Skateboards

Objectives:

The students will explore the interaction of two objects.
The students will demonstrate how Newton's Third Law applies to interacting objects

EALR:

1.1 Describe the average speed, direction of motion, and average acceleration of objects; for example: increasing, decreasing, or constant acceleration.
1.3 Understand the effects of balanced and unbalanced forces on the motion of objects along a straight line.
2.1 Study and analyze questions and related concepts that guide scientific investigations.
2.1 Use evidence from scientific investigations to think critically and logically to develop descriptions, explanations, and predictions.
2.1 Formulate and revise scientific explanations and models using logic and evidence; recognize and analyze alternate explanations and predictions.
3.1 Know why science involves testing, revising, and occasionally discarding theories, how inquiry and investigations lead to better understanding of the natural world, and why inquiry cannot lead to absolute truth.

Materials:

2-Skateboards or low friction carts

Procedure:

1. Have the students perform and observe the following situations.
2. Record the observations.

Situation 1:

Have two students about the same size face each other while standing on skateboards. Have them place their hands together palms facing and have the students push-off from each other.

Situation 2:

Have two students about the same size face each other standing on the skateboards. Have them place their hands together palms facing and have one student push the other student.

Situation 3:

Have two students face each other while standing on skateboards. One of the students is heavier than the other student. Have them place their hands together palms facing and have push-off from each other.

Situation 4:

Have two students face each other while standing on skateboards. One of the students is heavier than the other student. Have them place their hands together palms facing and have the heavier student push the lighter student.

Situation 5:

Have two students face each other while standing on skateboards. One of the students is heavier than the other student. Have them place their hands together palms facing and have the lighter student push the heavier student.

Data:

Report on Third Law Situations

Describe the set-up.

Predict what you expect to happen.

Describe what happened.

Diagram the forces involved.

Analysis:

1. List who moved in each situation.

2. What was the initial speed of each person in each situation?

3. If the person starts at rest then begins to move, is the motion constant or accelerated?

4. What causes an object to accelerate?

5. Can a person cause himself/herself to accelerate by pushing on himself/herself?

6. In situation 2, the person doing the pushing also moves. If a person can't cause themselves to accelerate, where does the force come from that causes them to accelerate?

7. Compare the motion of both people in situation 2?

8. What does this tell you about the force each person exerts on the other person?

9. In situation 3, which person had the greatest acceleration?

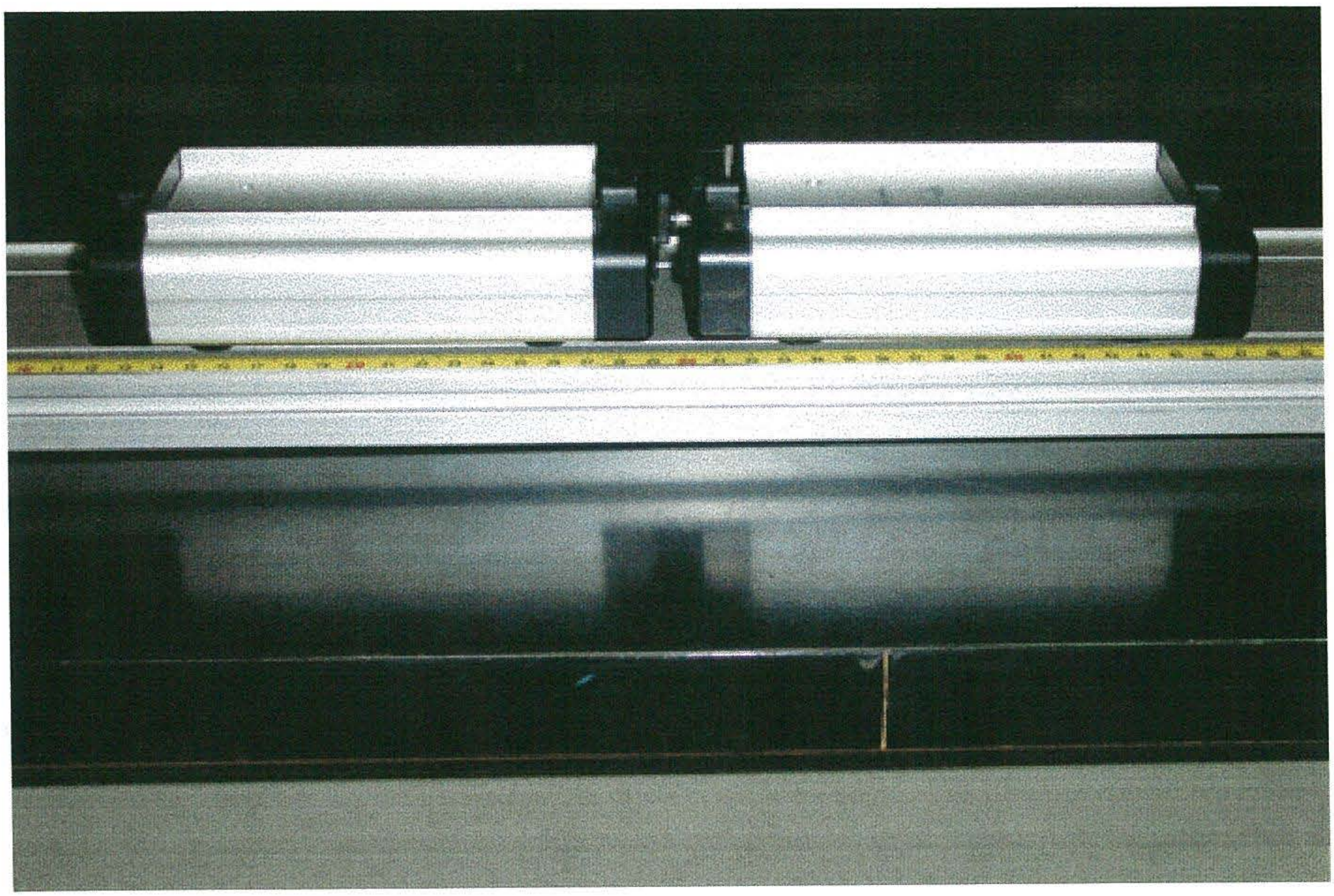
10. Using Newton's Second Law, does this mean that the heavier person pushed with a greater force?

11. Do equal forces always affect objects the same in every situation?

12. Do situations 4 and 5 indicate that the person pushing exerts a greater force or may the forces exerted on each person be the same?

13. According to Isaac Newton, if an object exerts a force on another object the second exerts an equal but oppositely directed force on the first. Do these situations support Newton or not? Please explain your answer.

Newton's Third Law with Carts



Newton's Third Law

Objective:

The students will demonstrate how forces acting on two objects cause a difference in motion.
The student will apply Newton's Third Law even when reactions don't seem equal.

EALR:

1.3 Know the factors that determine the strength of various forces.
1.3 Identify various forces and their relative magnitudes and explain everyday situations in terms of force.
1.3 Explain the effects of unbalanced forces in changing the direction of the motion of objects.
2.1 Formulate and revise scientific explanations and models using logic and evidence; recognize and analyze alternate explanations and predictions.
3.1 Know why science involves testing, revising, and occasionally discarding theories, how inquiry and investigations lead to better understanding of the natural world, and why inquiry cannot lead to absolute truth.

Materials:

Dynamics Cart | Collision Cart | Track
Masses

Procedure:

Part I

1. Level the track.
2. Push the plunger all the way in on the Dynamics Cart.
3. Place the cart on the track and release the plunger.
4. Record your observations.
5. Place the Dynamics Cart's plunger against the Collision Cart.
6. Release the plunger and observe the speed of cart.
7. Record your observation.
8. Add a mass to the Collision Cart and repeat steps 2 through 5.
9. Add another mass to the Collision Cart and repeat steps 2 through 5.
10. Continue until you have added four masses.

Part II

1. Take the masses our of the Collision Cart. Redo the lab adding the masses to the Dynamics Cart.

Data:

Observation from step 4

Record the relative velocities of the carts. (same, slower, faster)

Part I

Added Mass	Dynamics Cart	Collision Cart
None		
1		
2		
3		
4		

Part II

Added Mass	Dynamics Cart	Collision Cart
None		
1		
2		
3		
4		

Analysis:

1. Did the cart accelerate when the plunger was released without being against something?

2. What causes the carts to accelerate?

3. Is the source the same for both carts? Explain.

4. If the action of the plunger causes the acceleration, which cart does it push against?

5. What is the evidence that there is a force on the carts?

6. Must there be a force on both carts? Give evidence.

7. If the plunger pushes on the collision cart, what is the source of the force on the dynamics cart?

8. Why does this force arise?

9. From the trials you did with no added mass what does the acceleration of the carts suggest about the size of the force on each cart?

10. Is it reasonable to assume the plunger exerts approximately the same force? Why or why not?

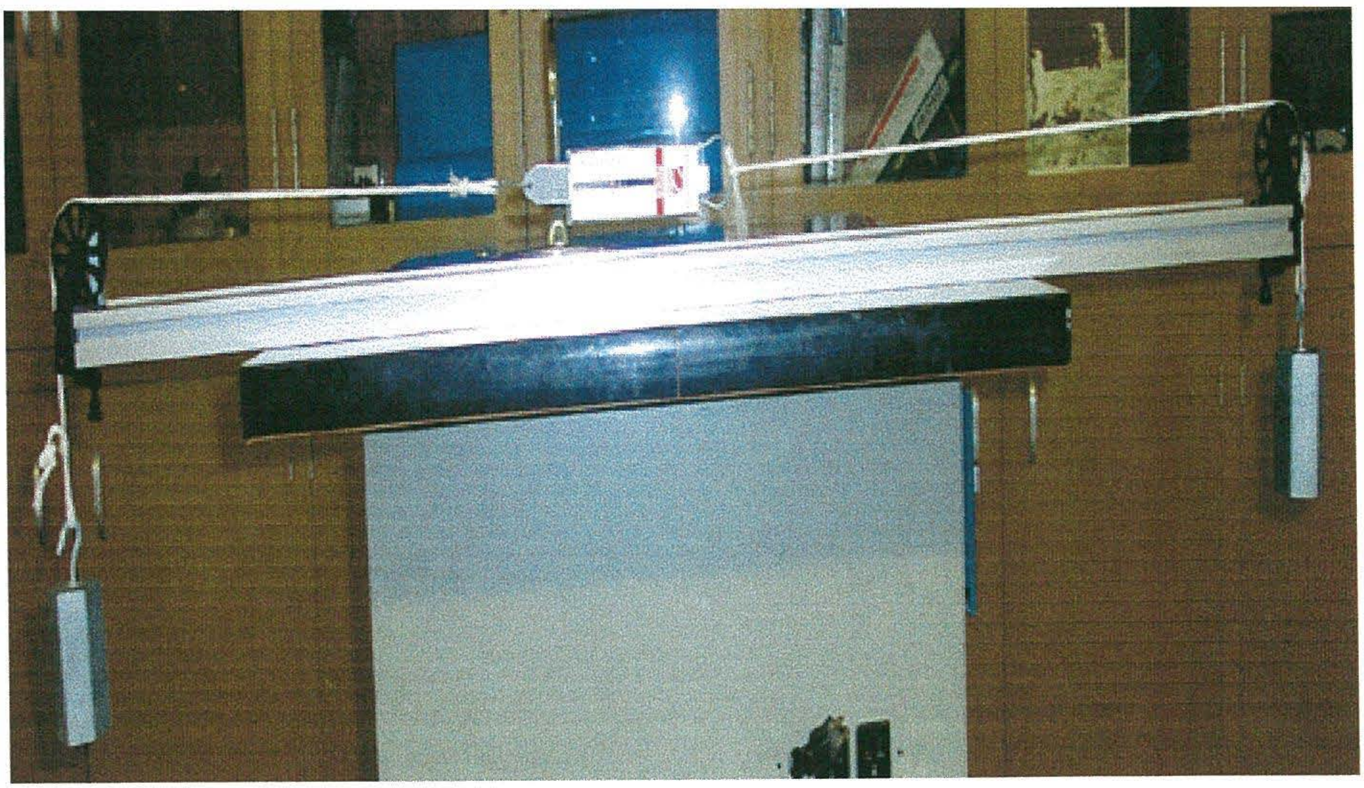
11. What happened to the acceleration of the collision cart as you added mass?

12. What happened to the acceleration of the of the dynamics cart as you added mass?

13. Explain why the acceleration was less as you added mass.

14. Newton's Third Law asserts that for every action force there is an equal but oppositely directed reaction force. Though the force may be the same size does the reaction always appear the same? Use this inquiry to explain your answer.

Tension on a Rope



Tension on a Rope

Objective:

The students will demonstrate the tension on a rope caused by hanging masses.

The students will use Newton's Third Law to explain the tension on the rope.

EALR:

1.3 Understand the effects of balanced and unbalanced forces on the motion of objects along a straight line.

1.3 Explain the effects of unbalanced forces in changing the direction of the motion of objects.

2.1 Use evidence from scientific investigations to think critically and logically to develop descriptions, explanations, and predictions.

2.1 Research, interpret, and defend scientific investigations, conclusions, or arguments; use data, logic, and analytic thinking as investigative tools; express ideas through oral, written, and mathematical expression.

Materials:

Scale 2-pieces of heavy cord 2-equal masses 2-pulleys

Procedures:

1. Make sure the scale is adjusted to read zero when no force is applied.
2. Attach each piece of cord to each end of the scale.
3. Attach one cord to a stationary object or the edge of the table.
4. Thread the other cord through the pulley and with one mass attached to the end allow the mass to hang over the edge of the table. (see diagram A)
5. Record the reading of the scale.
6. Predict what will happen if you remove the cord from the stationary object, attach it to a second mass and allow the mass to hang over the edge of the table, (see diagram B) record data in section.
7. Now remove the cord, attach the mass, and hang the mass over the table.
8. Record the scale reading.

Diagram A

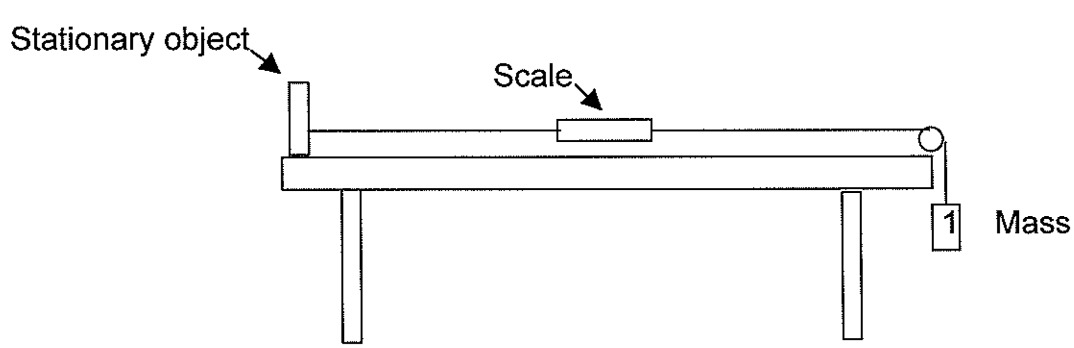
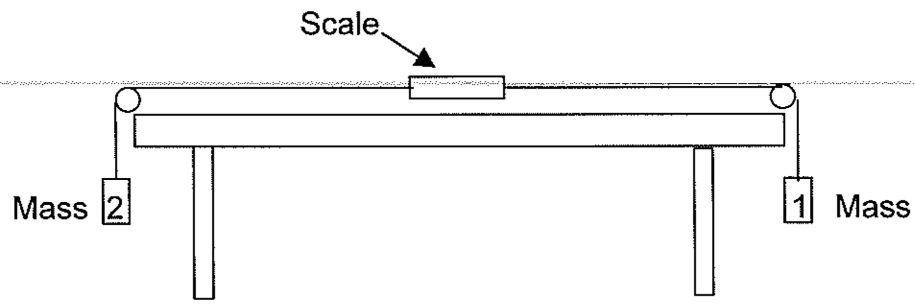


Diagram B



Data:

Scale Reading Step 5 ______________ N

Prediction:

Scale Reading Step 8 ______________ N

Analysis:

1. Was your prediction correct?

2. How did the scale reading from step 5 compare to the reading from step 8?

3. Draw a diagram of the forces acting on the scale in Diagram A.

4. What is the size of the force that mass one applies to the scale?

5. The scale is not accelerating so what must be the force on the scale by the string attached to the stationary object?

6. Draw a diagram of the forces acting on the scale in Diagram B.

7. What is the size of the force of mass one on the scale?

8. What is the size of the force of the mass two on the scale?

9. How does the size of the force of mass two compare to the force being exerted by the stationary object?

10. What keeps the masses from falling to the floor?

11. In diagram A, looking at mass one, what holds the string so it can hold the mass?

12. In diagram B, looking at mass one, what holds the string so it can hold the mass?

13. Newton's Third Law says that if one object pulls another the second object pulls back with an equal force. Does this inquiry support or reject this idea? Explain.

Newton's Third Law with Skateboards and Ropes

Newton's Third Law with Skateboards and Ropes

Objectives:

The students will explore the interaction of two objects.

The students will demonstrate how Newton's Third Law applies to interacting objects

EALR:

1.1 Describe the average speed, direction of motion, and average acceleration of objects; for example: increasing, decreasing, or constant acceleration.

1.3 Understand the effects of balanced and unbalanced forces on the motion of objects along a straight line.

2.1 Study and analyze questions and related concepts that guide scientific investigations.

2.1 Use evidence from scientific investigations to think critically and logically to develop descriptions, explanations, and predictions.

2.1 Formulate and revise scientific explanations and models using logic and evidence; recognize and analyze alternate explanations and predictions.

3.1 Know why science involves testing, revising, and occasionally discarding theories, how inquiry and investigations lead to better understanding of the natural world, and why inquiry cannot lead to absolute truth.

Materials:

2-Skateboards or low friction carts Rope

Procedure:

1. Have the students perform and observe the following situations.
2. Record the observations.

Situation 1:

Have two students about the same size face each other while standing on skateboards. Stretch a rope between them and have both of them pull on the rope.

Situation 2:

Have two students about the same size face each other standing on the skateboards. Stretch a rope between them and have one of them pull on the rope.

Situation 3:

Have two students face each other while standing on skateboards. One of the students is heavier than the other student. Stretch a rope between them and have one of them pull on the rope.

Situation 4:

Have two students face each other while standing on skateboards. One of the students is heavier than the other student. Stretch a rope between them and have the heavier student pull the lighter student.

Situation 5:

Have two students face each other while standing on skateboards. One of the students is heavier than the other student. Stretch a rope between them and have the lighter student pull the heavier student.

Data:

Report on Third Law Situations

Describe the set-up.

Predict what you expect to happen.

Describe what happened.

Diagram the forces involved.

Analysis:

1. List who moved in each situation.

2. What was the initial speed of each person in each situation?

3. If the person starts at rest then begins to move, is the motion constant or accelerated?

4. What causes an object to accelerate?

5. Can a person cause himself/herself to accelerate by pulling on himself/herself?

6. In situation 2, the person doing the pulling also moves. If a person can't cause themselves to accelerate, where does the force come from that causes them to accelerate?

7. Compare the motion of both people in situation 2?

8. What does this tell you about the force each person exerts on the other person?

9. In situation 3, which person had the greatest acceleration?

10. Using Newton's Second Law, does this mean that the heavier person pulled with a greater force?

11. Do equal forces always affect objects the same in every situation?

12. Do situations 4 and 5 indicate that the person pulling exerts a greater force or may the forces exerted on each person be the same?

13. According to Isaac Newton, if an object exerts a force on another object the second exerts an equal but oppositely directed force on the first. Do these situations support Newton or not? Please explain your answer.

Newton's Car

Objective:

The students will apply Newton's second and third laws of motion.

EALR:

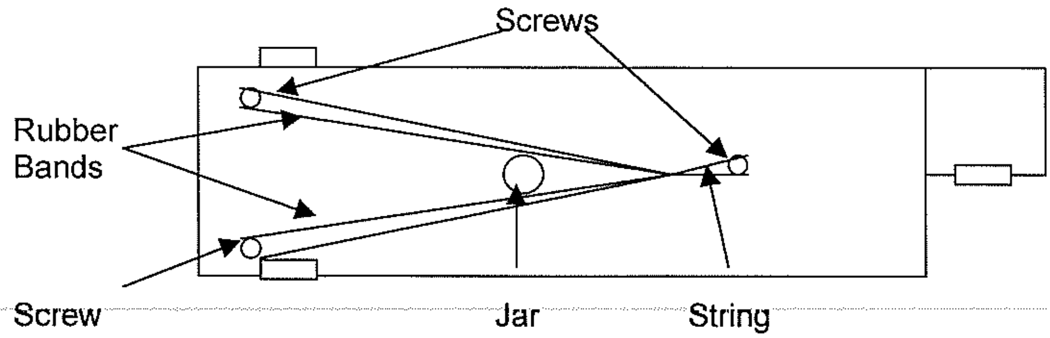
1.3 Identify various forces and their relative magnitudes and explain everyday situations in terms of force.
1.3 Understand the effects of balanced and unbalanced forces on the motion of objects along a straight line.
2.1 Use evidence from scientific investigations to think critically and logically to develop descriptions, explanations, and predictions.
2.1 Use mathematics, computers, and/or related technology to model the behavior of objects, events, or processes.
2.1 Research, interpret, and defend scientific investigations, conclusions, or arguments; use data, logic, and analytic thinking as investigative tools; express ideas through oral, written, and mathematical expression.

Materials:

- Wooden cart with wheels
- Plastic jar or film canister
- Three rubber bands
- Weight material (sand, washers, masses, etc.)
- Meter stick
- Matches
- Cotton string

Procedure:

1. Tie the string into 12 loops about inch in diameter. Make sure the loops are the same size.
2. Fill the jar or canister with material to add weight to the jar.
3. Measure the mass of the jar. Record in data table.
4. Set up the mass on the cart so that the mass is against one rubber band that is held by the cotton loop to the third screw. See diagram
5. Light the string on fire by the ends of the knot and stand back.
6. Measure how far the cart moves and record.
7. Repeat steps 4-6 using two rubber bands. Make sure the jar is always at the same release point.
8. Repeat steps 4-6 using three rubber bands.
9. Add 2 mass bars to the carts and repeat steps 4-7.
10. Empty the jars and add a new material to them so they have a different mass.
11. Repeat steps 3-8.
12. Graph your results with the distance on the y-axis and the number of rubber bands on the x-axis. Graph all your trials on the same set of axis but make sure you mark each one clearly.



Data:

Part I:
Mass of the Jar: ____________________ g.

# rubber bands	Distance no weight added to car (cm)	Distance weight added to car (cm)
1		
2		
3		

Part II:
Mass of the Jar: _________________ g.

# rubber bands	Distance no weight added to car (cm)	Distance weight added to car (cm)
1		
2		
3		

Analysis:

1. Each rubber band adds force. How does the distance the car moves relate to the added force?

2. As you added weight to the car, how did the added weight affect the distance traveled for a given force?

3. Contrasting the data from Part 1 and Part 2, how did changing the mass of the jar affect distance?

4. According to Newton, acceleration is directly proportional to the force applied and inversely proportional to the mass. Do the data from this exercise support or counter this idea?

5. Draw a diagram of the forces acting on the cart.

6. Draw a diagram of the forces acting on the jar.

7. Explain why the car goes one way and the jar goes the other.

8. Does it seem reasonable that the rubber band would apply the same force everywhere?

9. How does the size of the force of the rubber bands on the jar compare to the size of the force of the rubber bands on the car?

10. How does the mass of the jar compare to the mass of the car?

11. Use the difference in mass to explain why the jar goes farther than the car?

12. How does Newton's Third Law of Motion apply to the jar and the car?

Block and String

Block and String

Purpose:

This demonstration will show how mass affects the transfer of force.

Procedure:

1. Hang a large weight from a sturdy support with a string.

2. Then attach another string of the same size to the bottom of the block.

3. Ask the students to predict which string will break if you pull on the bottom string.

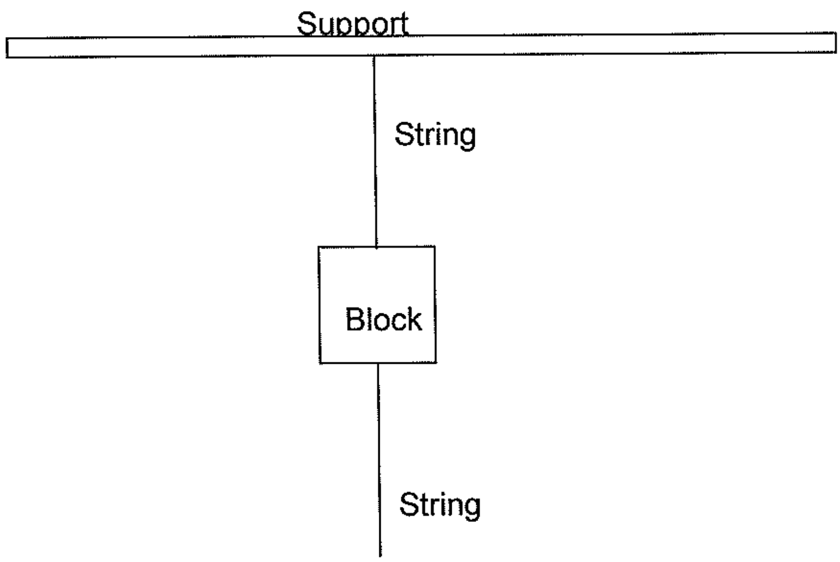
4. Pull slowly to break the top string. Pull the string rapidly to break the bottom string.

5. Repeat the demonstration, breaking the opposite string as in step 4.

A twist to this demonstration:

1. Drop the block with a string attached to the bottom of the block

2. Jerk the string straight down as the block is falling. Again the string will break.



Report on Demonstrations

You may use a drawing to describe the set-ups for the demonstrations, but you should also use words.

Describe the set-up.

Predict what you expect to happen and why.

Describe what happened.

Write an explanation of how the demonstration works.

How might this relate to other demonstrations you have seen?

Leading questions

1. What forces are being applied to the two strings?

2. What happens to the force on the top string as you slowly pull on the bottom string?

3. So as you slowly pull on the bottom string why does the top string break?

4. Now, when you jerk on the bottom string the bottom string breaks. What is between the bottom string and the top string?

5. What must be the effect of the block on the transfer of force between the strings?

6. Could you say the block resist being moved?

7. This idea of resistance to motion was part of Newton's First Law of Motion. State in your own words what seems to be true of an object at rest.

8. Looking at the block that was dropped, what forces were applied to the string?

9. Did the block resist speeding up?

10. Was there any force applied to the block that would be strong enough to account for this resistance? If so state the force.

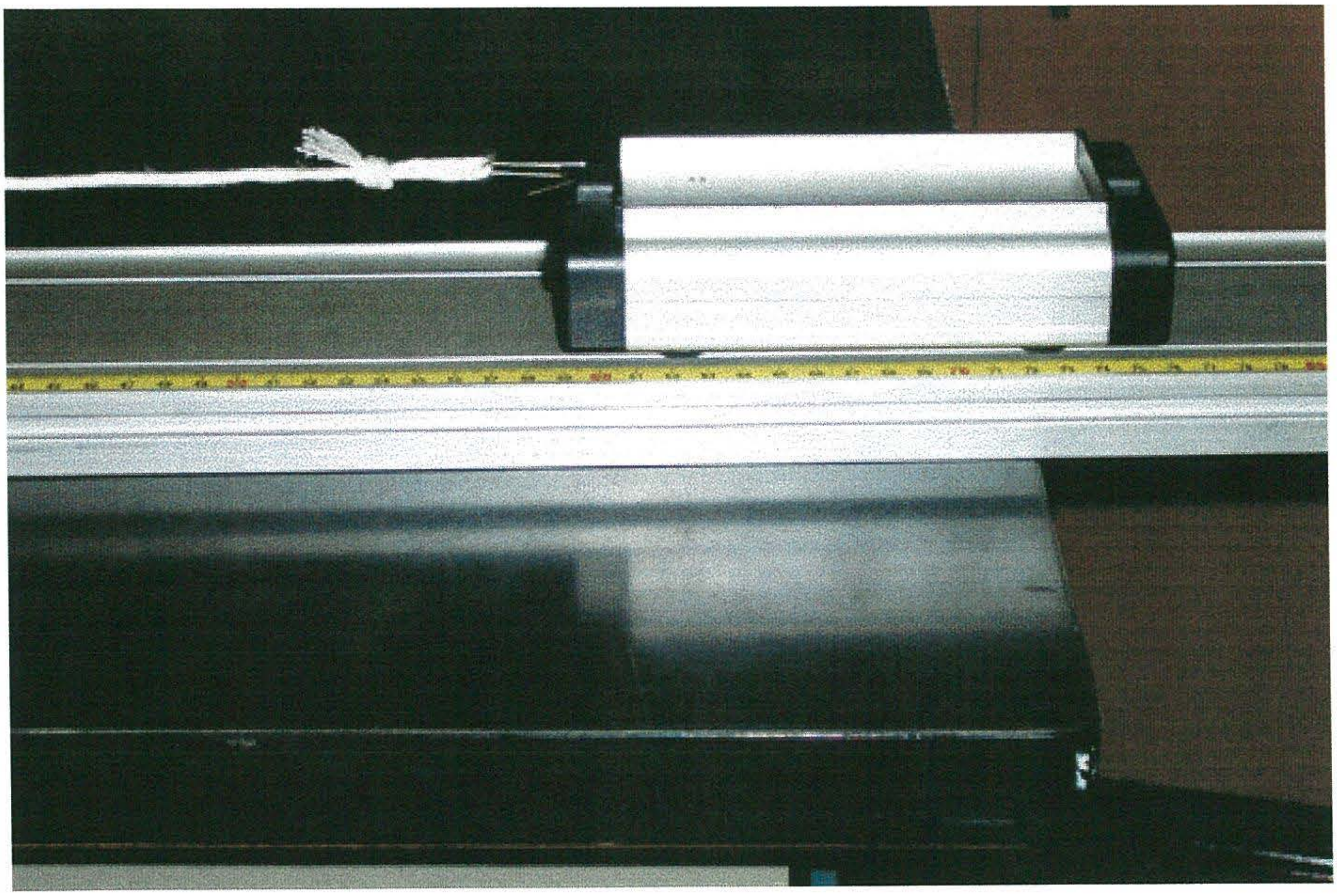
11. A resistance to change in motion by a moving object is part of Newton's First Law of Motion. State in your own words what seems to be true about an object in motion.

12. Restate your rules for an object at rest and an object in motion as one rule.

13. What is needed to overcome this resistance to not changing an object's state of motion?

14. Restate your rules for an object at rest and an object in motion as one rule including what is necessary to overcome this resistance.

Low Friction Inertia



Low Friction Inertia

Purpose:

This demonstration will show that friction has very little to do with inertia and things moving also resist change in motion.

Procedure:

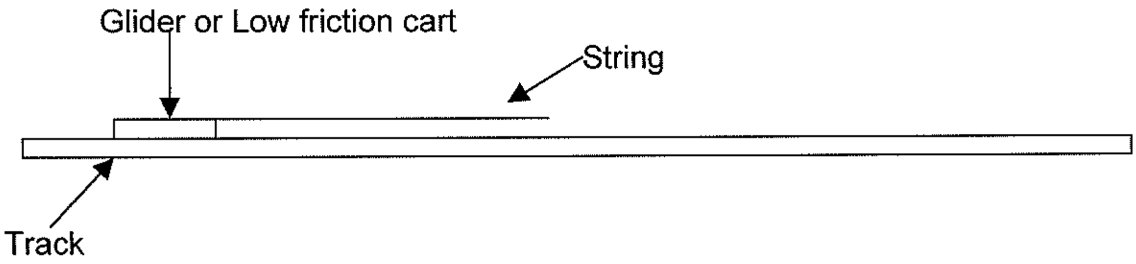
1. Set glider on an air track or use some kind of low friction cart.

2. Attach a light string to the glider or cart.

3. Pull the string slowly and the glider or cart will move.

4. Give the string a quick jerk and it will break.

5. Try the demonstration but have the glider or cart moving before the string is jerked.



Report on Demonstrations

You may use a drawing to describe the set-ups for the demonstrations, but you should also use words.

Describe the set-up.

Predict what you expect to happen and why.

Describe what happened.

Write an explanation of how the demonstration works.

How might this relate to other demonstrations you may have seen?

Leading Questions

1. Relatively speaking, how much friction does the glider or cart have?

2. Is it reasonable to assume the friction would be greater when you jerk on the string compared to pulling slowly?

3. Does the glider or cart seem to resist moving or is another force involved?

4. State a rule that seems to apply to objects that are sitting still and are being pulled.

5. What happened to the string when the glider or cart was moving and the string was given a jerk?

6. Does the effect of jerking the string seem to be the same whether the object is moving or not?

7. Is there a frame of reference in which the glider or cart is not moving?

8. Newton claimed that an object has a natural tendency to resist a change in motion, does this inquiry help support this idea?

Inertia Block

Inertia Block

Purpose:

This demonstration will show the effects of inertia.

Procedure:

1. Attach a length of heavy string to a 10-lb. block so that it forms a loop.
2. Place the block on rollers so that it moves along the table freely.
3. Attach a fine thread to the loop and pull the block slowly.
4. Now use a hammer to violently jerk on the heavy string.

Mc-3. INERTIA BLOCK

Illustration from The Learning Team

Report on Demonstrations

You may use a drawing to describe the set-ups for the demonstrations, but you should also use words.

Describe the set-up.

Predict what you expect to happen and why.

Describe what happened.

Write an explanation of how the demonstration works.

How might this relate to other demonstrations you may have seen?

Leading Questions

1. Relatively how much friction does the block have?

2. Is it reasonable to assume the friction would be greater when you jerk on the string compared to pulling slowly?

3. Does the block seem to resist moving or is another force involved?

4. State a rule that seems to apply to objects that are sitting still and are being pulled.

5. Newton claimed that an object has a natural tendency to resist a change in motion, does this inquiry help support this idea?

Reducing the Effect of Force

Reducing the Effect of Force

Purpose:

This demonstration will show how inertia reduces the effect of a force.

Procedure:

1. Lay your hands palm – down of a table.

2. Place a pile of bricks on your hand. You may want to cover your hands with a cloth or cover the bricks to avoid scratching your hand.

3. Have someone hit the top brick hard enough to break it.

Alternative

1. Place a pile of books on the head of someone that sitting.

2. Place a board on the pile of books.

3. Drive a nail into the board.

Report on Demonstrations

You may use a drawing to describe the set-ups for the demonstrations, but you should also use words.

Describe the set-up.

Predict what you expect to happen and why.

Describe what happened.

Write an explanation of how the demonstration works.

How might this relate to other demonstrations you may have seen?

Leading Questions

1. What would happen if you set the brick directly on your hand and tried to break it?

2. Would you say the presence of the pile of bricks somehow protected the hand?

3. How much do the bricks want to move?

4. Is the mass of the pile larger than a single brick?

5. Does the same force have the same effect on a small mass and a large mass?

6. Could you say that because the pile is more massive it won't tend to move as easily?

7. Write as rule that seems to relate the mass of an object with its tendency to move.

8. Does your rule agree with Newton's First and Second Laws of Motion?

Balloon Car

Objective:

The students will use their knowledge of force and motion to design a car that is powered by a balloon.

EALR:

2.2 Design, conduct, and evaluate systematic and complex scientific investigations, using appropriate technology, multiple measures, and safe approaches.

2.2 Research, model, simulate, and test alternative solutions to a problem.

2.2 Propose, revise, and evaluate the possible constraints, applications, and consequences of solutions to a problem or challenge.

Materials:

2 Soda straws
4 small plastic lids
A bamboo skewer
Tape
Scissors
Small lightweight tray 10 – 15 cm long like a restaurant take – out tray
Balloon

Description:

In Class:

Have the students form teams of two and give them 20 minutes to construct the cars. They can only use the material given to them. Set up a course so all the students can start at the same time and mark off a line three meters from the start line. Points are awarded for the car that goes the farthest. Additionally, points may be rewarded for the first car to cross the three – meter line.

At Home:

Have the students design their own balloon powered cars using any number of balloons and materials they would like. The car must not be a model from a store. The following competitions could be used to award points.

Drag race – the fastest time over a short distance.

Longest distance traveled.

Climbing – the car that can go up the steepest slope.

Tractor pull – the cars are attached by string and are sent in opposite directions. The car that moves the farthest from the starting line when both cars are out of air is the winner.

Paper Airplanes

Objective:

The students will use their knowledge of force and motion to design a paper airplane.

EALR:

2.2 Design, conduct, and evaluate systematic and complex scientific investigations, using appropriate technology, multiple measures, and safe approaches.
2.2 Research, model, simulate, and test alternative solutions to a problem.
2.2 Propose, revise, and evaluate the possible constraints, applications, and consequences of solutions to a problem or challenge.

Description:

Allow students to work in pairs to build airplanes made from one 8.5" x 11" piece of typing paper and 3cm of tape. The students will be allowed one period to design and test their planes. The competition will be the next day. They may want to use various Internet sites to get ideas for construction. Hold competitions in the following areas:

Longest distance from start to finish

Time the plane stays in the air

Aerobatics

Plastic Bottle Car

Objective:

The students will use their knowledge of force and motion to design a car made from a plastic bottle.

EALR:

2.2 Design, conduct, and evaluate systematic and complex scientific investigations, using appropriate technology, multiple measures, and safe approaches.
2.2 Research, model, simulate, and test alternative solutions to a problem.
2.2 Propose, revise, and evaluate the possible constraints, applications, and consequences of solutions to a problem or challenge.

Materials:

Plastic bottle
Wheels
Axles
Tape
Scissors
Propellant (air, carbon dioxide)

Description:

The students working in small groups will design a car made from a plastic bottle. They need to figure out how to attach wheels to the bottle and how they are going to power it. They will be allowed class time to do research. The construction should be limited to one class period.

Competitions include:

Drag race – the fastest time over a short distance.

Longest distance traveled.

Climbing – the car that can go up the steepest slope.

Tractor pull – the cars are attached by string and are sent in opposite directions. The car that moves the farthest from the starting line when both cars are out of propellant is the winner

Chapter V

Summary, Conclusions, and Recommendations

Summary

The aim of this project was to create activities that General Science teachers could use to supplement their units on motion and Newton's Laws of Motion. During my years of teaching I noticed students could quote back laws and concepts dealing with motion but had little ability to apply them to new situations. A review of the literature showed that this was a common experience among educators in the fields of Physics and Physical Science. The review of the literature also revealed many articles that stated the problem and had ideas for solutions but most of the articles were aimed at the college level or at a High School Physics course. There were few practical examples of how to reach students in the early high school years. One of the problems seems to be the lack of ability of students to ask questions that lead to a deeper understanding of the situations they confront. Rather than creating a particular curriculum, I chose to create a collection of activities that could be used in a variety of units. Each activity has a complement of guiding question that will help students in self-assessment and guide them to understanding the current concepts of physics. The activities have included the Essential Academic Learning Requirements of the State of Washington.

Conclusion

It is not enough to have students doing hands - on activities. They must engage their minds to understand the concepts found in physics. Teachers need to find ways to encourage students to start asking questions that lead to a deeper understanding. In the literature several people (Hake, 1992; Heller, Keith, & Anderson, 1992; Hestenes, 1992; McDermott, 1996; Van Heuvelen, 1991) have developed ways of getting the students involved in asking questions. However, the methods they wrote about were aimed at college students. But after reading the literature and their success, it seemed reasonable to write questions that would help younger students to begin the process of asking questions about how they think before college. This project is a way of starting this process. These questions should also concentrate on qualitative ideas rather than quantitative problems. The idea is to get students to think about the concept not just the numbers and formulas.

Recommendations

There are many sources of hands-on exercises available to teachers but students need to be heads-on to learn concepts in physics. This project is only a beginning. Teachers need to design each unit with the idea of getting students to ask the questions that will help them gain an understanding of their own. The activities in this project should be used as a place to start. They should not be used to create a curriculum but as an addition or part of it. Other activities also should be included and fit in to best reflect the needs of a particular class. Some of the inquiries may also be adapted as demonstrations. The teacher also needs to decide how students can best learn. For example, when using skateboards to explore Newton's Third Law of Motion it might be useful to have a different student fill in the report for each different situation and have the group get together to go over the analysis questions.

These activities may also be used as a practical assessment at the end of a unit. The activity using students pushing each other on skateboards may be used to teach Newton's Third Law but the activity using a rope and skateboards with students pulling may be used as a practical question on the assessment for the unit.

Though the questions are given at the end of the activities in a manner that can be used as a handout, as much as possible, given the constraints of a classroom, most of the questions would lend themselves to a dialog between student and teacher or between students in a group. In group settings these questions would only begin the dialog and may lead logically to other questions as different answers arise and new ideas from the students are presented.

Again I would like to stress these are example questions and the teacher needs to know the cultural diversity of the classroom and change questions to fit the cultural knowledge of the students. If students have no concept of linear time and distance it would be very difficult to understand the idea of velocity. The place to start would then have to include other activities that develop these concepts.

These are also activities that can be performed in a classroom. Real world examples should also be given and students should be given the opportunity to ask questions about how this relates to what they experience. For example, when teaching about inertia of a ball going around a plate, this can be related to a car going around a corner especially on icy roads. These real world situations may also be useful in setting up the activities in this guide. The situation with a car may be used to stimulate inquiry that leads to using the activity on inertia and curves.

This guide should be used as a spring-board to help encourage students to ask questions of themselves and others

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APPENDIX

This is a sample unit on Newton's Laws of Motion using some of the activities found in the project.

Day one

Objectives:

Students will introduced to the idea that, objects tend to stay in their present state of motion unless acted on by unbalanced forces

Procedure:

Introduce the old card, coin, and glass trick

Have set-ups so the students can perform the trick themselves.

Have the students try other objects and different kinds of cards.

Have them describe what happens with each try then write a hypothesis as to why the trick works or maybe sometimes doesn't work.

As a demonstration perform the two strings attached to a heavy weight demo.

Ask the students which string will break

First break the string that is opposite the one the students claim.

Then show depending on how you pull the bottom string the other one will break

Have students explain why it depends on how you pull the strings which string breaks.

Explain that there is the property of matter that things tend to want to stay at rest called inertia.

Ask students to make a connection between the card snap and the string.

Report for Card Trick

Demo: Teacher flicks a card from under a penny.

Describe what happens

Make a hypothesis as to why it happens.

Explore:

Try the trick yourself

Try removing the card slowly

What happened?

Give a possible explanation of the reaction.

Try the different cards.

Describe what happens and explain the reactions

Try different objects on top of the cards

Describe what happens and explain the reactions

Day two

Objectives:

Students will introduced to the idea that, objects tend to stay in their present state of motion unless acted on by unbalanced forces

Procedure:

Review the idea that things want to stay at rest.

Do several demos that show the idea again making each demo more dramatic. For each of the demonstrations the students should do the following:

a) Predict what they expect to see.
b) Describe what they see.
c) Make an explanation of what happened.
d) Try to relate the demonstration to previous demonstrations.

Have the students form groups and have one student from each group write their observations for one of the demonstrations. Then have the groups discuss the observations and come up with an explanation that holds for all demonstrations.

Demo 1

Inertial block

A length of window sash cord or clothesline rope is tied in a loop through an eye in a 10 lb. block which is free to slide along the table. A uniform pull will easily drag the block. A violent jerk with a hammer will always break the rope. If one wishes, the breaking strength of the rope may be measured. The experiment may be repeated with a very fine thread to show that the block can be moved with small forces and small accelerations

Mc-3. INERTIA BLOCK

Demo 2

Try the pulling a tablecloth from under a block or glass.

Demo 3

Use a handkerchief or cloth, several bricks, and a hammer. Lay your hand palm-down on the table. Spread the cloth over your hand to avoid scratches from the rough bricks. Stack several bricks on the back of your hand. With a hammer, strike the top brick hard enough to break it. The inertia of the bricks will prevent damage to your hand.

Or, use a hammer, nail, a soft wooden board, and heavy books. Let one student sit in a chair and hold the heavy block or books on his head. Put the board on top. Drive a nail into the board. The inertia of the board and books (or block) will absorb the blow and result in no discomfort to the student.

Demo 4

This leads to a demo of a block placed on the instructor's stomach while he is lying on a bed of nails. Students are then invited to hit the block with a large hammer.

Help the students make the connection that the tendency to stay-put is a property of matter.

Leave the students with the following demonstration to think about for the next class.

Tie one string to the bottom of the weight. Release the weight, then jerk the string. The inertia is such that, even while the weight is falling, the string breaks.

Report on Demonstrations

You may use a drawing to describe the set-ups for the demonstrations, but you should also use words.

Describe the set-up.

Predict what you expect to happen and why.

Describe what happened.

Write an explanation of how the demonstration works.

How might this relate to other demonstrations?

Day 3

Objectives:

Students will introduced to the idea that, objects tend to stay in their present state of motion unless acted on by unbalanced forces.

The student will demonstrate, how to describe motion using Newton's Laws of Motion with emphasis on the First Law.

Procedure:

The idea is to now make the connection between inertia at rest and inertia of a moving object.

Repeat the last demonstration from the day before.

Use the students' knowledge of frames of reference to show that constant velocity and rest are the same depending on a person's frame of reference.

Use an air track to show that the only time the glider slows down is when it strikes the ends.

Guide the students to extend the short distance of the track to infinity. Make sure the students know the difference between the forces that cause the initial motion and what happens before it hits the end.

Show a video of Galileo and how he extended his work with inclined planes to develop the idea of inertia.

Have the students formalize a statement that explains all the demonstrations and activities of the last three days.

The students can share their ideas in groups of three to five and write a group statement that includes their ideas.

Then have each group share their statements. Critique each statement leading the class to a formal statement of Newton's First Law

Present formal statement of Newton's First Law

An object at rest will remain at rest and an object in motion will remain in motion at a constant velocity unless acted on by unbalanced forces.

Explain that this is a property of matter that is called inertia and that mass is measure of the amount of inertia an object has.

Show the students the contrast between the idea of inertia and the Aristotle's idea that motion had to have a force behind it.

Day 4

Objectives:

The student will demonstrate, how to describe forces acting on an object.

The student will demonstrate, how to determine the Net Force acting on the object.

The student will demonstrate, the use of force diagrams to show the interaction of forces between objects.

Procedure:

The formalized statement of Newton's First Law contains the idea of unbalanced forces. This leads to the need for an explanation of force and how are they balanced.

First ask the students how they would define a force. Keep this a class discussion with any reasonable answer up for discussion. Usually the idea of pushing or pulling that causes a change in motion is presented.

Set a book on a table and ask the students to name the forces on the book.
Make sure when they say gravity to have them indicate what is exerting the force due to gravity.

Draw a picture of the situation on the board and then show them a separate diagram of the book. Diagram the forces acting on the book. Make sure you have the arrows the same length.

Explain that by making such diagrams it is easier to see the forces acting in the situation.
The students should see that as long as the force from the table and the gravitational force of the Earth are the same the book won't move because the initial velocity is zero and acceleration is zero. These are balanced forces but don't give a formal definition yet. The object here is to teach the students to draw force diagrams.

Have the students draw the forces acting on the table.
Remind them:
a) Identify the forces and their source.
b) Place the arrow on the diagram to indicate the direction of the force.
c) The length of the arrow should indicate the magnitude of the force.

Draw their results on the board

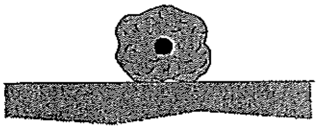
Have the students draw the diagrams for several situations on their own.

Force Diagrams

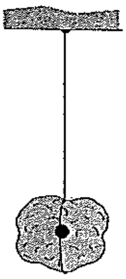
Name ______________________________

For each of the situations below draw the force diagram. Make sure the length of the arrows reflects the relative size of the forces. Have the arrows point in the direction of the force. Label each arrow stating the force it represents and the source of that force.

1) A rock sitting on the ground.

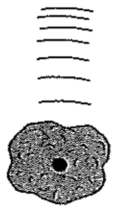


2) A rock suspended by a rope tied to a beam.



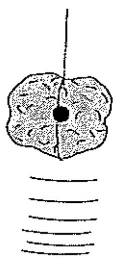
3) Diagram the forces on the rope in the picture for problem 2.

4) A rock is falling. Ignore air resistance.

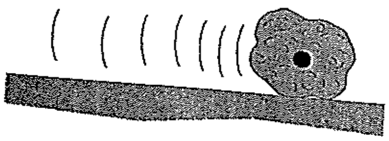


5) Include air resistance for the falling rock in problem 4. The rock is still accelerating.

6) A rock is pulled upward by a string.



7) A rock is being pushed along a rough surface at a constant speed.

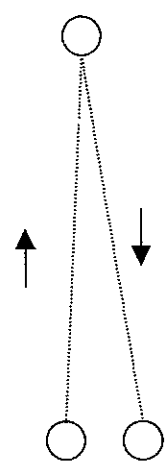


8) The rock in problem 7 is slowing down.

9) The rock in problem 7 is speeding up.

10) A ball is thrown into the air. Only consider the path after the ball leaves the hand and before it hits the ground.

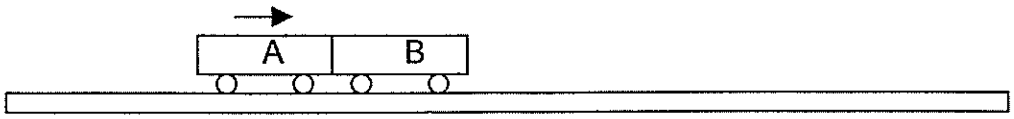
a) Diagram the forces that act on the ball as it moves upward.



b) Diagram the forces that act on the ball at the top.

c) Diagram the forces that act on the ball as it moves downward.

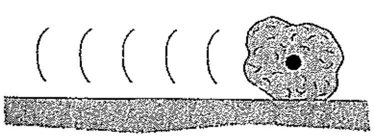
11) A cart collides with another cart.



a) Draw the forces acting on A.

b) Draw the forces acting on B.

12) A rock is sliding at constant speed on a frictionless surface.



Day 5

Objectives:

Students will introduced to the idea that, the change in an object's motion is proportional to the net force and inversely proportional to the objects mass.

The student will demonstrate, how to describe motion using Newton's Laws of Motion with emphasis on the Second Law.

Procedure:

Skateboard investigation

See the handout on the investigation. You mat need to explain the scale shows the force applied to the person.

The investigation should demonstrate that acceleration is inversely proportional to mass and directly proportional to force.

Skateboards and Newton's Second Law

PURPOSE: The purpose of this activity is to see if there is any relationship between mass, force and acceleration.

MATERIALS: Skateboards, low friction cart, or skates Bathroom scales

PROCEDURE:

1. Select a starting point and a finish line on a smooth, straight and level surface.

2. One student sits on the skateboard while the bathroom scale is placed against their back. This scale should be zeroed while against the student's back.

3. One member of the group should resist the rider in order to adjust to the desired force.

4. Another member of the group is selected as a pusher and must place their hands flat against the bathroom scale. This member must apply a force (a push) on the skateboard rider while they are being held in place. The pusher MUST maintain a constant force throughout the distance regardless of the temptation to push harder to get them going. On a prearranged signal the holder releases the rider and the group should observe what happens.

5. Record your observations. Catch the speeding skate boarder and repeat the experiment using a different force.

6. Repeat using different skateboarders (of different masses) or load down the original skateboarder. Record your observations.

DATA:

Use qualitative words rather than numbers to enter data.

Force	Acceleration		Mass	Acceleration
5			Light	
7			Medium	
10			Heavy	

ANALYSIS:

1. Draw a force diagram showing the forces on the skateboarder.

2. What effect did the increased force or push have on the acceleration of the skateboarder?

3. How does acceleration seem to be related to the mass of the rider for a constant force or push?

Day 6

Objectives:

Students will introduced to the idea that, objects tend to stay in their present state of motion unless acted on by unbalanced forces.

Students will introduced to the idea that, the change in an object's motion is proportional to the net force and inversely proportional to the objects mass.

The student will demonstrate, how to describe motion using Newton's Laws of Motion

The student will demonstrate, how to describe forces acting on an object

Procedure:

Review what the students have learned so far.

a) No net force is needed to keep an object in motion.
b) How to draw force diagrams.
c) Acceleration is related to mass and the force applied.

Have students use Pasco dynamics carts and tracks to investigate this relationship again.
(See handout)

Newton's Second Law

Purpose:

To demonstrate the relationship between force, mass, and acceleration

Materials:

Dynamics cart | Track | Extra masses
Photogate timer

Procedure:

1) Attach a 10-cm card to the Dynamics cart.

2) Set the cart on the track while the plunger is fully extended against the stop at the end of the track.

3) Set the photogate timer so the photogate is just ahead of the card.

4) Depress the plunger one notch.

5) Place the cart on the track with the plunger against the stop.

6) Set the timer to record the time it takes for the card to pass through the gate.

7) Release the cart by striking the plunger release the pin.

8) Record the time in the table.

9) Repeat steps 4 through 8 three times.

10) Average your results.

11) Find the velocity by dividing 10 by the average time.

12) Depress the plunger two notches and repeat steps 5 through 11.

13) Depress the plunger three notches and repeat steps 5 through 12.

14) Depress the plunger three notches, add a mass bar to the cart and repeat steps 5 through 11.

15) Depress the plunger three notches, add two mass bars to the cart and repeat steps 5 through 11.

Data:

Force	Time 1	Time 2	Time 3	Average Time	Velocity
1					
2					
3					

Mass of the cart = 500 g   Mass of one bar = 500 g

Mass	Time 1	Time 2	Time 3	Average Time	Velocity
500 g					
1000 g					
1500 g					

Analysis:

1) Draw a force diagram for the cart.

2) The cart is standing still at the beginning of this investigation, so we can say the change in velocity is equal to the final velocity. For the purpose here, we may assume the time for each push by the plunger is approximately the same and we can call this time equal to 1. The acceleration then becomes equal to the final velocity.

a. Graph the acceleration on the Y-axis and the force on the X-axis.
Is the slope of the graph positive or negative?

b. Graph the acceleration on the Y-axis and the mass on the X-axis.
Is the slope of the graph positive or negative?

c. Graph the acceleration on the Y-axis and the inverse of the mass on the X-axis.
Is the slope of the graph positive or negative?

3) From the graphs what can you say about the relationship between force, mass, and acceleration?

Day 7

Objectives:

Students will introduced to the idea that, the change in an object's motion is proportional to the net force and inversely proportional to the objects mass.

The student will demonstrate, how to describe forces acting on an object.

The student will demonstrate, how to determine the Net Force acting on the object.

The student will demonstrate, the use of force diagrams to show the interaction of forces between objects.

Procedure:

Give the students time to finish their analysis of the lab from day 6.

Show the students how their graphs indicate the relationship between force, mass, and acceleration.

Introduce a formal definition of Newton's Second Law

The acceleration of an object is directly proportional to the net force applied and inversely proportional to the mass.

$$\text{Acceleration} = \frac{\text{Net force}}{\text{Mass}} \qquad \text{Net force} = \text{mass X acceleration}$$

Using the first formula

a) Ask what would happen to the acceleration if the Net force increased or decreased?
b) Ask what would happen to the acceleration if the mass increased or decreased?
c) Ask if the Net force = 0 what is the acceleration? Relate this to Newton's First Law.

Use the book-on-the-table example to show the idea of Net force.

a) Start with a force diagram.
b) Show the Normal force from the table is equal to the force of gravity from the Earth.
c) The Nat force then is the difference of the two forces because they are acting in opposite directions.
d) Because the Net force = 0 the forces are said to be balanced and the acceleration is zero.

Now drop the book

a) Have the students draw a force diagram for the book.
b) Ask them if air resistance is greater than, equal to, or less than the force due to gravity.
c) Is the difference of the forces equal to zero?
d) Because the Net force doesn't equal zero the forces are said to be unbalanced and there is an acceleration.
e) From observation is the book accelerating?
f) Because the forces are unbalanced and the Net force is not zero the object accelerates.

Give the students a handout of qualitative problems to solve dealing with Newton's First and Second Laws of Motion.

Qualitative Questions on Newton's Laws

Name ______________________________

1) If you were in outer space and threw a ball, how much force would be required to keep it moving? Explain.

2) If someone catches the ball in problem one, must a force be exerted to stop it? Explain.

3) If an object is not moving, does that mean no forces are acting on it? Explain.

4) If a cart is moving at a constant velocity, does a force have to be applied to it? Explain.

5) When a ball is rolled across a level table, the force of gravity doesn't speed it up, but when the ball is dropped, the force of gravity does speed it up. Why?

6) If an object has forces applied to it, must it always accelerate? Explain.

7) If a lab cart is moving at a constant velocity while being pushed by a force of 5 Newtons, what is the force of friction? Draw a force diagram.

8) What is the inertia of a 500-kg rock?

9) How many objects are the forces acting on in Newton's First and Second Laws of Motion.

10) A box is sitting on the floor, two people are pulling on the box one from the right the other from the left. If the people are pulling with the same force, draw the force diagram for the box.

Day 8

Objectives:

Students will introduced to the idea that, the change in an object's motion is proportional to the net force and inversely proportional to the objects mass.

The student will demonstrate, using $F_{Net} = ma$ to find the magnitude of change in motion.

The student will demonstrate, how to determine the Net Force acting on the object.

The student will demonstrate, the use of force diagrams to show the interaction of forces between objects.

Procedure:

Review the handout from day 7, if necessary give the students time to work on the handout.

Extend the qualitative problems to quantitative problems.

Example 1:
A 2-kg rock is accelerating at $10 m/s^2$ as it falls through the air. Find the force on the rock.

Have the students do a similar problem on their own. Review.

Example 2:
A 2-kg rock is accelerating under the influence of air resistance and gravity. Air resistance = 4 N and force due to gravity = 20 N

a) Find the Net force on the rock.
b) Find the acceleration of the rock.

Example 3:
Demonstrate forces acting on a block that is being pulled on a surface.

a) Have the students identify the forces involved and diagram them.
b) Have the students see that the Normal force and gravity produce an acceleration of zero.
c) Provide the students with numbers for friction and the applied force, then have them find the acceleration of the block.

Have the students solve another problem of two forces acting on a single object.

Review.

Have students do a handout with quantitative forces.

Problems for Newton's Second Law

Name ______________________________

Show all your work. List knowns, show the equation used to solve the problem, show the numbers in the equation, and give the answer with the proper label. In problems 5 - 8 you should draw a diagram.

1) What is the force applied to a 1-kg object giving it an acceleration of $1 m/s^2$.

2) A 1000-kg car accelerates at $5 m/s^2$, what is the force being applied to the car?

3) A 250-N force is applied to a 50-kg sled that is on a frictionless surface, what is its acceleration?

4) A 150-N force is applied to a 75-kg roller-skater, what is the skater's acceleration?

5) A force of 50 N is applied to move a cart on a track. If friction is 30 N, what is the net force on the cart?

6) A 10-kg block of wood is sitting on a table. A force of 100 N is applied to the block and friction is 70 N.

a) What is the net force on the block?

b) What is the acceleration of the block?

7) A 1500-kg car that is stationary starts to move. After 5 seconds the car is moving at 15 m/s.

a) If the acceleration is uniform, what is the rate of acceleration?

b) What is the Net Force on the car?

8) A 7000-kg plane is launched from an aircraft carrier in 2 seconds by a constant force of 350,000 Newtons.

a) What is the plane's acceleration?

b) What is the plane's final velocity?

Day 9

Objectives:

Students will introduced to the idea that, all forces come in pairs.

Students will introduced to the idea that, interacting objects apply forces that are equal and opposite.

The student will demonstrate, how to describe forces acting on an object.

The student will demonstrate, how to distinguish between Third-law pair and balanced forces.

Procedure:

Review the handout from day 8. If necessary give the students time to work on the handout.

Review the idea that so far we have looked at forces acting on one body. This leads to balanced and unbalanced forces and the acceleration that unbalanced forces cause.

Return to the book-on-the-table problem.

a) Show the force diagram for the book.
b) Show the force diagram for the table.
c) Show the students the relationship between the force on the book by the table and the force on the table by the book.

Procedure:

1. Have the students perform and observe the following situations.
2. Record the observations.

Situation 1:

Have two students about the same size face each other while standing on skateboards. Have them place their hands together palms facing and have the students push=off from each other.

Situation 2:

Have two students about the same size face each other standing on the skateboards. Have them place their hands together palms facing and have one student push the other student.

Situation 3:

Have two students face each other while standing on skateboards. One of the students is heavier than the other student. Have them place their hands together palms facing and have push-off from each other.

Situation 4:

Have two students face each other while standing on skateboards. One of the students is heavier than the other student. Have them place their hands together palms facing and have the heavier student push the lighter student.

Situation 5:

Have two students face each other while standing on skateboards. One of the students is heavier than the other student. Have them place their hands together palms facing and have the lighter student push the heavier student.

Third Law Demos

Describe the set-up.

Predict what you expect to happen. Explain.

Describe what happened.

Diagram the forces involved.

Write an explanation of the reaction seen in this demonstration.

Day 10

Objectives:

Students will introduced to the idea that, all forces come in pairs.

Students will introduced to the idea that, interacting objects apply forces that are equal and opposite.

The student will demonstrate, how to describe forces acting on an object.

The student will demonstrate, how to distinguish between Third-law pair and balanced forces.

The student will demonstrate, using $F_{Net} = ma$ to find the magnitude of change in motion.

Procedure:

Discuss the students' conclusions from the day before. If necessary give them to finish the group discussion.

The idea is to get the students through force diagrams and explanations to see that the interactions of the skateboarders are explained by the fact that they apply the same force to each other no matter who appears to be applying the force. This is true even of the reaction between the student and the skateboard.

Have the students perform an investigation with Collision carts, Dynamics carts, and masses.
(See handout)
The students should get the idea that the plunger will always produce approximately the same force. But as mass is added to one cart, the reaction isn't the same. This is easily seen from Newton's Second Law relating force, mass, and acceleration.
Have the students discuss their findings in class.

Introduce a formal statement of the Third Law.
When one object exerts a force on another object, the second object exerts an equal but oppositely directed force on the first.

Newton's Third Law

Purpose:

Demonstrate how forces acting on two objects cause a difference in motion.
Newton's Third Law applies even when reactions don't seem equal.

Materials:

Dynamics Cart   Collision Cart   Track   Masses

Procedure:

1) Level the track.
2) Push the plunger all the way in on the Dynamics Cart.
3) Place the Dynamics Cart's plunger against the Collision Cart.
4) Release the plunger and observe the speed of cart.
5) Record your observation.
6) Add a mass to the Collision Cart and repeat steps 2 through 5.
7) Add another mass to the Collision Cart and repeat steps 2 through 5.
8) Continue until you have added four masses.
9) Take the masses off the Collision Cart and redo the lab only add the masses to the Dynamics Cart.

Data:

Record the relative velocities of the carts. (same, slower, faster)

Added Mass	Dynamics Cart	Collision Cart
None		
1		
2		
3		
4		

Added Mass	Dynamics Cart	Collision Cart
None		
1		
2		
3		
4		

Analysis:

1) Does the force applied by the plunger change during the investigation?

2) Does the plunger apply the same force to both carts?

3) Explain why the heavier cart moves slower?

Day 11

Objectives:

Students will introduced to the idea that, objects tend to stay in their present state of motion unless acted on by unbalanced forces.

Students will introduced to the idea that, the change in an object's motion is proportional to the net force and inversely proportional to the objects mass.

Students will introduced to the idea that, all forces come in pairs.

Students will introduced to the idea that, interacting objects apply forces that are equal and opposite.

The student will demonstrate, how to describe motion using Newton's Laws of Motion

The student will demonstrate, how to describe forces acting on an object

The student will demonstrate, how to distinguish between Third-law pair and balanced

forces

Procedure:

Review Newton's three laws of motion.

Use the Newton's car investigation to show how the three laws work together to explain a somewhat complicated situation.

Newton's Car

Purpose:

To demonstrate Newton's second and third laws of motion

Materials:

- Wooden cart with wheels
- Plastic jar or film canister
- Three rubber bands
- Cotton string
- Meter stick
- Weight material (sand, washers, masses, etc.)
- Matches

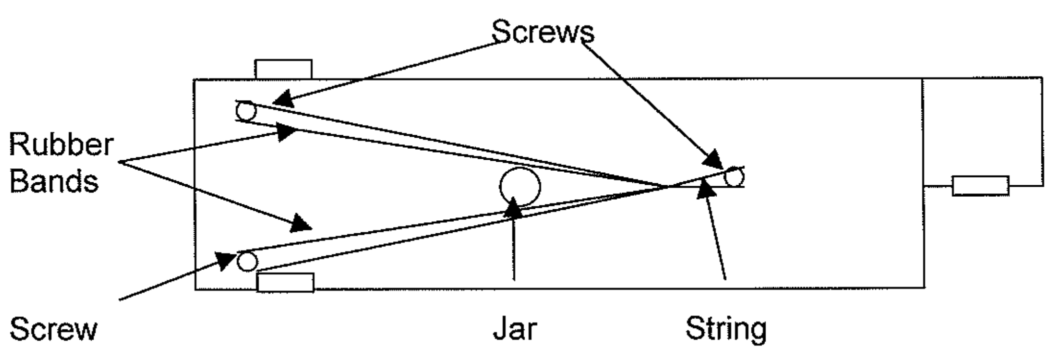
Procedure:

1. Tie the string into 12 loops about inch in diameter. Make sure the loops are the same size.
2. Fill the jar or canister with material to add weight to the jar.
3. Measure the mass of the jar. Record in data table.
4. Set up the mass on the cart so that the mass is against one rubber band that is held by the cotton loop to the third screw. See diagram
5. Light the string on fire by the ends of the knot and stand back.
6. Measure how far the cart moves and record.
7. Repeat steps 4-6 using two rubber bands. Make sure the jar is always at the same release point.
8. Add 2 mass bars to the carts and repeat steps 4-7.
9. Empty the jars and add a new material to them so they have a different mass.
10. Repeat steps 3-8.
11. Graph your results with the distance on the y-axis and the distance on the x-axis. Graph all your trials on the same set of axis but make sure you mark each one clearly.

Data:

Mass ________________ g.   Mass _______________ g

# rubber bands	Distance no weight (cm)	Distance added weight (cm)		# rubber bands	Distance no weight (cm)	Distance added weight (cm)
1				1		
2				2		
3				3		



Day 12

Objectives:

Students will introduced to the idea that, all forces come in pairs.

Students will introduced to the idea that, interacting objects apply forces that are equal and opposite.

The student will demonstrate, how to describe forces acting on an object.

The student will demonstrate, how to distinguish between Third-law pair and balanced forces.

Procedure:

Have students discuss their findings from day 11's investigation. In particular, what do the graphs show. Also, what forces are involved in the cart moving forward while the can moves backward.

Have the students do the following investigation.

a) Suspend a mass over the edge of the table holding it in place with a string and scale attached to a stationary object.
b) Have students record the reading on the scale.
c) Now replace the stationary object with another mass the same size suspended over the other edge of the table.
d) Have the students record the reading on the scale.
e) Have the students explain why the scale reads the same.
    Hint: Draw a diagram showing all the forces and look for third law pair.

Set up a similar situation with two students playing tug-of-war in front of the class. But, have a scale attached to the ends of the rope and a scale in the center showing the tension on the rope.

Again lead a discussion of why all the scales read the same. Draw the forces on the board.

Show the students it is situations like these that demonstrate that the Third Law provides a consistent explanation.

Have the students think of other examples of how Newton's Laws of Motion can be used to explain situations that are difficult to see.

Day 13

Objective:

Students will introduced to the idea that, all objects attract each other with a force directly proportional to their masses and inversely proportional to the square of the distance between them - Law of Gravity.

The student will demonstrate, a knowledge of Newton's Law if Universal Gravitation.

Procedure:

Expand Newton's Laws of Motion to gravity.

Demonstrate the obvious, falling objects accelerate.

Ask students how this relates to Newton's Second Law.
Drop two objects of different mass to show they accelerate at the same rate.
If acceleration is the same for both objects and the mass is different, what is true about the applied force?

The force on the larger object must be larger.

F= ma then becomes W= mg where W is weight and g is the acceleration due to gravity.

This leads to the idea that mass and weight are not the same thing.

Go through the formula to show the students that they are related that is if you are on Earth g doesn't change so the more mass the larger the weight. Also show that if the same mass is moved to a different location, say the moon, the acceleration due to gravity changes so the weight changes.

Do an example for the students.

Show a short video on the Law of Gravity

a) It is universal. All objects attract every other object but usually it is very small.
b) The larger the masses the greater the attraction.
c) The greater the distance the smaller the attraction by the square of the distance.

Give students a handout on weight and mass also gravitational attraction.

Gravitational Force

Name ______________________________

Use 10 m/s^2 as the acceleration due to gravity on the Earth.
Show your work.

1) What is the weight of a 75-kg person?

2) An astronaut has the mass of 50 kg.

a) What is the astronaut's weight on the launch pad?

b) At 6400 km the astronaut is twice as far from the center of the Earth as when on the launch pad. What is the weight of the astronaut?

c) What is the acceleration due to gravity at that point in space?

3) The astronaut continues through the Solar System. Fill in the following chart. M = 50 kg

	Weight (N)	Acceleration from gravity (m/s^2)
Moon		1.7
Mercury	200	
Venus		8.6
Mars		3.7
Jupiter	1150	
Saturn	450	
Uranus		8
Neptune		11
Pluto	15	

4) The force of gravity between two 20,000-kg balls is .1N.

a) What would the force of gravity be if one of the balls was 40, 000 kilograms?

b) What would the force of gravity be if one of the balls was 10, 000 kilograms?

5) What would happen to your weight if you double your mass?

6) The force of gravity between two objects that are 2 meter apart is 16 newtons.

a) What would happen to the force if the distance is increased to 4 meters?

b) What would happen to the force if the distance is increased to 8 meters?

c) What would happen to the force if the distance is decreased to 1 meter?

Day 14

Review

Day 15

Assessment

Retake the pretest

Give the students some examples from life and have them explain the situations using Newton's Laws.