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RICE SCHOOL FRICTION EXPERIMENT

An Interactive Qualifying Project Report

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by

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ABSTRACT

The purpose of this interactive qualifying project was to design a set of friction experiments for the fifth grade at Rice School in Holden, MA. The experiments were designed in accordance with the constructivist model of learning and implemented teaching strategies found in relevant literature. The experiments were tested on a pilot group of Rice students and found to fulfill the intended objectives.

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CHAPTER 1 - INTRODUCTION

Public ignorance in regard to science is an overwhelming problem in today's society. A few years ago a chemist was frustrated to learn that the San Diego Freeway was closed for eight hours by the County Environmental Health Department after a truck dropped a labeled bag of iron oxide, whose particles then spilled out across the highway.[1] The officials responsible for shutting down the highway described the iron oxide as toxic, dangerous, and flammable in open air. Most high school chemistry courses presumably teach students that "rust," or iron oxide, is indeed safe for handling and not flammable in open air. Even without high school chemistry, most adults should know that rust occurs naturally on iron surfaces.

Public ignorance regarding science does not begin in high school; rather, it takes root through the inappropriate ways science is taught in grade school. Grade school science education has been considered sub-par for years. The different causes have been debated for equally as long and different solutions have been attempted. The transmission method of teaching relies upon information being presented by the teacher or the textbook and the students absorbing this information. This method is conducive to the use of many different vocabulary words with no real evident application being presented to describe science concepts, and students are required to remember the meanings much like in a foreign language course. The meanings represent nothing more than words to the students; an average fifth grader can not understand what an atom is and the forces and phenomena involved. The student may remember the word "atom," and may even remember that atoms are the "building blocks of matter," but the student will certainly not be able to explain how atoms bond or behave in any other general fashion. A promising solution to this problem is to demonstrate the meaning of the words to the students through tangible lessons.

Constructivism, a concept that works with tangible lessons and "hands-on" learning involves learners actively constructing their own knowledge by using their existing knowledge to interpret new information in ways that make sense to them. As a result, learners build their own conceptual structures which subsequently foster the development of some conceptions and inhibit the development of other incorrect ideas that could be picked up through a transmission model.[2] Constructivism works by expanding knowledge based on prior knowledge, but the tangible or concrete lessons are crucial to a fifth grader's basic understanding of science concepts. A chemistry student will remember more clearly what happens when an acid and a base are mixed if that student carries out the reaction in a lab setting as opposed to reading the results of that reaction in a book. The rapidly boiling result would be "hands-on" learning of a most dramatic sort.

The state of Massachusetts developed a new grade school science curriculum last year. The curriculum contains goals for the students to reach, instructional strategies that the teacher might use, and suggestions for appropriate learning activities such as experiments and demonstrations.[3] The instructional strategies are general suggestions to help teachers (the teacher may…). The learning activities are open-ended suggestions of possible student experiments or activities that might construct scientific knowledge, but the activities are not well defined. The curriculum encourages teachers to design activities that are constructivist in nature, but the teachers are granted quite a bit of leeway in determining the precise form of their lessons.

Mr. Skillings at the Rice School in Holden, MA, determined an area in his curriculum that needed attention and contacted WPI to offer this area as potential project material. He provided the specific goal of this project. This was to develop a science kit conforming to the fifth grade science curriculum, which clearly defined and demonstrated the concept of friction. This concept was to be understood both in qualitative and in quantitative terms. The central influence on the design was making the experiment accessible and interesting to the fifth grade students performing it while promoting constructive learning and avoiding the transmission method. This guided the initial design formation and subsequent revisions. Chapter 2 covers the most relevant literature that was found and summarizes key issues in educational methods. Chapter 3 presents the lesson protocol used for the experimental visits and the debriefing from those visits. Chapter 4 covers the results of the visits and an analysis of the design, and chapter 5 presents conclusions on the project.

CHAPTER 2 - LITERATURE REVIEW

"That science has long been neglected and declining in England is not an opinion originating with me, but is shared by many, and has been expressed by higher authority than mine... Some portion of the neglect of science in England may be attributed to the system of education we pursue... Scientific knowledge scarcely exists among the higher classes of society. The discussions in the House of Lords or the House of Commons which arise on the occurrence of any subjects connected with science sufficiently prove this fact. It so very rarely happens that men in public situations are at all conversant even with the commonest branches of scientific knowledge... The public, and even men of sound sense and discernment, can scarcely find means to distinguish between the possessors of knowledge merely elementary, and those whose acquirements are of the highest order."[4]

Charles Babbage wrote the previous paragraph in 1830, in his essay titled "Reflections on the decline of Science in England and on some of its Causes." This is interesting because it shows that there has been little change in the level of concern over public ignorance regarding science, because the ignorance was caused at least partially by the educational system, and because even "educated people" could not distinguish between the scientifically literate and the scientifically ignorant. Why Babbage did not blame the educational system entirely for the public ignorance is unclear. It would seem evident that people cannot understand what they have not learned, so inadequate education must be a root cause.

The following quote makes the leap into modern times where the cause of the problem has been narrowed down to the educational system. "Nonetheless by the middle

1980's we were again told that there was a crisis in science education. The National Science Foundation, the U.S. Department of Education, the American Association for the Advancement of Science, the American Medical Association, the Carnegie Foundation, and other prestigious groups during the past decade have issued some three hundred reports with titles such as "A Nation at Risk" or "Today's Problems, Tomorrow's Crises." They stress the urgency of the problem of science illiteracy."[5] The problem as realized in the 1980's was a lack of interest in science, and a decline in the nation's science aptitude when compared to other nations. As of 1989, the September issue of "Science" magazine stated that science literacy among American adults today has not surpassed its 1957 level.[6] Considering the technological advances between 1957 and 1989, the apparent educational results are extremely poor.

Literacy can be defined in several different ways, each seeming appropriate when applied to different subjects. One view is that once one has assimilated a large enough vocabulary pertaining to a particular subject, that person has become literate in that subject. This view is consistent with the transmission learning methods used too often today in grade school science courses. The students can learn their entire required vocabulary and may even be able to form complete grammatically correct sentences, but they do not necessarily understand what it is they are discussing. This in fact suggests that if a person can create an image of literacy, that person is literate, a point to which Babbage took exception in 1830.

That science literacy is a problem is obvious and evident. The solution to the problem lies in finding the point at which a student begins to lose interest in science, finding out why that student begins to lose interest, and getting the student interested, or interested once again. A large amount of introductory science information is presented in grade school and junior high. This is intended to give the student a general base of knowledge that can be expanded with more technical knowledge later in the educational process. The following is a quote from physicist and educator Uri Haber-Schaim: "Professor Paul Hurd has observed that many of the recent science texts for the middle school and junior high school introduce as many as 2,500 technical and unfamiliar terms per text, twice as much as a foreign language text! And let's remember that most of the words in a foreign language text are the equivalent of known words in the student's mother tongue."[7] Science cannot be explained without the specialized vocabulary describing different phenomena. However, Haber-Schaim believes the teacher effectively loses the student by not demonstrating or establishing the different phenomena that the specialized vocabulary words describe. A student confused about a subject at an early age may not ask questions, or may not be capable of asking the right questions needed to overcome any confusion caused by the jumble of new words. This could cause a lack of interest, and in turn, continued ignorance.

As summarized by J. Mestre in his article on pre-college physical science, "Two main instructional practices are found in American education: One is prevalent, while the other is emerging. We have all experienced the prevalent practice, which results from the so-called transmission model of instruction. In this model, students are exposed to content through lectures, presentations and readings, and are expected to absorb the transmitted knowledge in ready-to-use form."[8] The one major assumption within the transmission model is that all information is transmitted as the teacher intends it to be. This often proves to be erroneous and confuses students when teachers add transmitted knowledge on top of previously garbled transmissions. The student is left with pockets of coherent information that do not fit together to form a realistic overview of science.

Mestre goes on to state an alternative to traditional practice, "Unlike the transmission model, the second major instructional practice, which has emerged over the last decade, begins with what is commonly termed the constructivist model of learning, constructivist epistemology, or simply constructivism. This model contends that all of our knowledge is the result of our having constructed it. The construction of knowledge is a lifelong, effortful process. At any time, the corpus of knowledge we have constructed makes sense to us and helps us interpret or predict events in our experiential world... constructivism contends that students are not sponges ready to absorb and use transmitted knowledge; the knowledge already written on their mental slates affects how they interpret new observations and how they accommodate newly acquired knowledge."[9] The teacher needs to be aware of the student's accumulated knowledge of a particular subject that is being discussed and to work with that knowledge to maintain uniformity and the construction of correct ideas. Constuctivism builds on previous knowledge, taking it one step further each time. Grade school teachers have the unique experience of being the first to lay the building blocks for a student's education in many areas, and what better way to do this than by associating physical models and hands-on experience with theoretical concepts.

California recently adopted controversial new standards setting the newest scientific vocabulary that children must learn to be considered literate. According to the California standards for third grade physical science, students are responsible for the following information: "Matter has three forms: solid, liquid, and gas... Evaporation and melting are changes that occur when the objects are heated... All matter is made of small particles called atoms, too small to see with our eyes... There are over 100 different types of atoms which are displayed on the periodic table of elements."[10] Some concepts in the California Standards, such as atoms and molecules, which are briefly discussed but not explained, are purposely avoided by the National Academy of Science's recommended standards until high school. Many science education reformers attack the California Standards saying that they focus too much on detailed knowledge instead of the more general concepts that are fundamental to a solid scientific understanding.[11] Applying a concept developed by Paiget that recognizes the need for concrete situations to be handled before abstract situations suggests that throwing words like atom and element at third graders will produce nothing more than confusion, because those concepts are totally out of a child's frame of reference.[9]

Third grade students are far from having the ability to handle abstract thought processes. Exploring concepts that are so far from being tangible leaves the student with no choice but to accept the new information on faith. Knowledge of atoms and the periodic table of elements would be a difficult lesson to teach through any means because there is too large a gap between any knowledge the third graders might possess and that needed to understand atoms. The Transmission Model would be suitable for "teaching" third graders about atomic facts and vocabulary because they can memorize the definitions and repeat them back through testing. At best, however, this creates only the illusion of knowledge.

The "hands-on" approach is not without problems either. The following is from an article titled "Teaching Science in Fifth Grade: Instructional Goals That Support Conceptual Change:"

"We see what this is all about now." one said. "You are trying to get us to think and learn for ourselves."

"Yes, yes." replied the teacher, heartened by the long delayed breakthrough. "That's it exactly."

"Well," said another student, "we don't want to do that."[12]

These were fifth grade students presented with an experiment designed to lead the students to actively construct knowledge for themselves. This illustrates a vital consideration: the experiments have to be fun for the students, or at the very least, interesting, so that the students want to participate in an active way.

Uri Haber-Schaim's article "Are We Teaching Science" compares today's science curricula to a physical education class that confines the students to their desks memorizing the rules and terminology of a sport. His point is that the physical education curriculum needs to include actual physical activity such as "playing soccer on the field and experiencing how the rules manifest themselves in practice."[9] No phys ed course would be without physical activity, so why should a science course be without experimental scientific activity? The content of phys ed includes the rules and statistics while the process is playing the game. Comparing this analogy to science, "First, there are real science teachers debating the scholarly sounding question of content versus process. This question is a non-question. The process of science is part and parcel of the content of science. The principles of science, without the empirical evidence for them, and without the understanding of their range and validity, become just another dogma with a specialized vocabulary whose dictionary-like definitions are mechanically memorized."[13]

A "Hooking Run" is a specific pattern a soccer player might run in order to receive the ball from a teammate. The pattern involves running downfield and cutting back in a certain manner to receive the ball. Perhaps the description on paper would be too difficult for someone who has never played soccer before to understand. That is why going out on the field and making the run a few times to show an inexperienced player would be much more effective than telling the player to read the description above, a few more times. This project attempts to create a "playing field" for fifth grade students to learn about friction. A teacher can tell students that heavier objects experience more friction, and that rough surfaces produce more friction, and that smoother surfaces produce less friction, but the students may not understand the concept until they pull on an object that is heavier, or rougher, or smoother and feel the difference for themselves.

CHAPTER 3 - METHODOLOGY

Overview

The problem addressed in this project was stimulated by the new Massachusetts Science Curriculum, which was created in 1998 and appears in Appendix A. The curriculum identifies specific science topics to be taught to all fifth graders, and these topics are presented in the form of desired outcomes, together with suggested teaching approaches and experiments to perform, but without any guidance in the form of detailed lesson plans or experimental procedures. There are eleven different desired outcomes outlined in the physical science curriculum. For example, the desired Outcome #8 specifies that students will be able to build a simple circuit using a battery, bulbs, and wires, subsequently expanding the circuit to include switches, buzzers, and motors. The instructional strategy is to "Explain procedure and model the assembly of circuits." The learning activity is to "Create closed and open circuits – draw schematic diagrams and demonstrate same." These guidelines supply a goal and suggest a procedure, but they do not supply a set of lesson plans or step-by-step procedures! The lack of step-by-step procedures or strict detail is where the potential for this project appeared.

Mr. Skillings identified three outcomes where he needed something extra to complement his lesson plans and contacted WPI with these three areas listed as the backbone of the project description. These three outcomes are that the student will define friction, the student will define the relationship between friction and force, and the student will use a spring scale to measure friction between chosen sliders and surfaces. The suggested activities for the outcomes are in Appendix A and are located next to the outcomes. They were useful in providing a general direction to pursue with the design.

Mr. Skillings, a fifth grade teacher at the Rice School in Holden, MA, initiated this project by selecting the topics he wanted help in addressing with an appropriate set of new lesson plans. Interviews with Mr. Skillings provided the starting point for development of the prototype, using his suggestions and general guidelines he set down for constructing the kit. He wanted some sort of sliding device that could allow the students to take measurements of the friction between two surfaces using a spring scale. A few of his suggestions or brainstormed ideas are written on the fifth grade science curriculum in Appendix A. The next step was to go to the research literature to find out about proper curriculum design and educational methods.

The more relevant information found during the research is summarized in the preceeding chapter. The plan then was to take the research results and apply them to the design of the science kit intended to illustrate the nature of forces and friction. The culmination of the prototype design was to produce something that simplified the treatment of friction to the point where it was isolated enough to be the only variable in the situation. Once this was accomplished, the students would have the opportunity to see the effects of friction on a flat plane and be able to assign numbers to different situations through measurement.

Friction experiments that were actually published showed in detail the use of an inclined plane to demonstrate the forces acting on the block: "Once students have a thorough "picture" or model of the physics of the situation, doing the accompanying math becomes a matter of applying algebraic formulas."[14] The inclined model was too advanced for the fifth grade students to understand, but the "picture" mentioned was relevant to the design of the kit. They realized that something was pulling back on the block, and, in a few years, when someone shows them an incline and asks what is holding the block on it, they may remember the force measured by the spring scale. This lesson was too advanced for the fifth grade kit, but the notion of using blocks and an inclined plane further developed the initial design ideas.

The initial design that was tested consisted of a plank, a pulley, a sled with a string attached, different weights, and different surfaces for the sled to move over. By "weights," what are being referred to are the 100 gram slabs used to increase the mass of the sled. Strictly speaking, the gram is a mass unit, but the 100 gram slabs were referred to as weights to avoid the confusion that the fine distinction between mass and weight would certainly cause. The different materials were teflon, metal, wood, and sandpaper of varying grit sizes. The testing consisted of hanging weights from the string drawn over the pulley until the sled sitting on top of the frictional surface began to move. Additional weights were then added to the sled and the testing process was repeated. This was done in 50 gram increments from 0 to 500 grams extra on the sled. See Appendix A for a photo of the initial prototype. The initial testing results can be seen on the next page in Figure 1.

The results represent two test runs done at each weight for each material. The general trends were very favorable for continuing development in the direction of the slider/surface approach. Each different run at the same weight did not end up with perfect results, but rather, the results were similar and predictable to a general degree because of the distinct trends shown by the measurements. The teflon surface has the least friction because it requires the smallest pulling forces, the wood and metal surfaces are intermediate, and the sandpaper surfaces are most frictional. Furthermore,

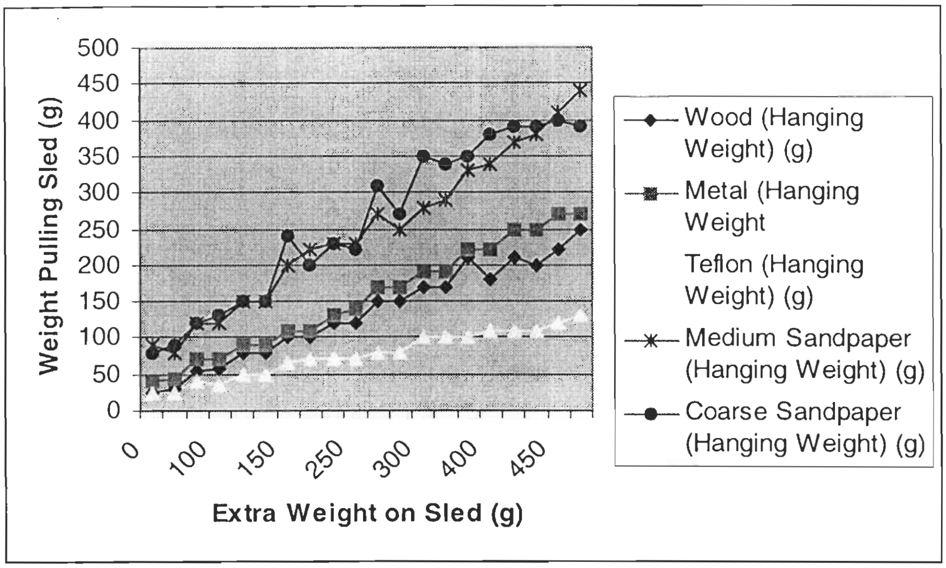

Figure 1 - Results of Initial Testing

the testing continued by hanging weights on the string attached to the sled until it broke the static friction force, and it became increasingly clear that the hanging weight approach would prove too slow and tedious to maintain the interest of the fifth grade students. The spring scale had not yet been incorporated into the lesson as required by the curriculum, because it was feared that the spring scale would be difficult to read and operate in a repeatable fashion. Testing was required to allay this fear; it needed to be shown that it was possible to achieve repeatable results with the spring scale before handing it to the fifth grade students and asking them to identify the trends and characteristics of the experiments. The results of the spring scale testing were encouraging enough to discontinue the use of the hanging weights. Figure 2 shows the results produced by comparing the data from the sled on fine

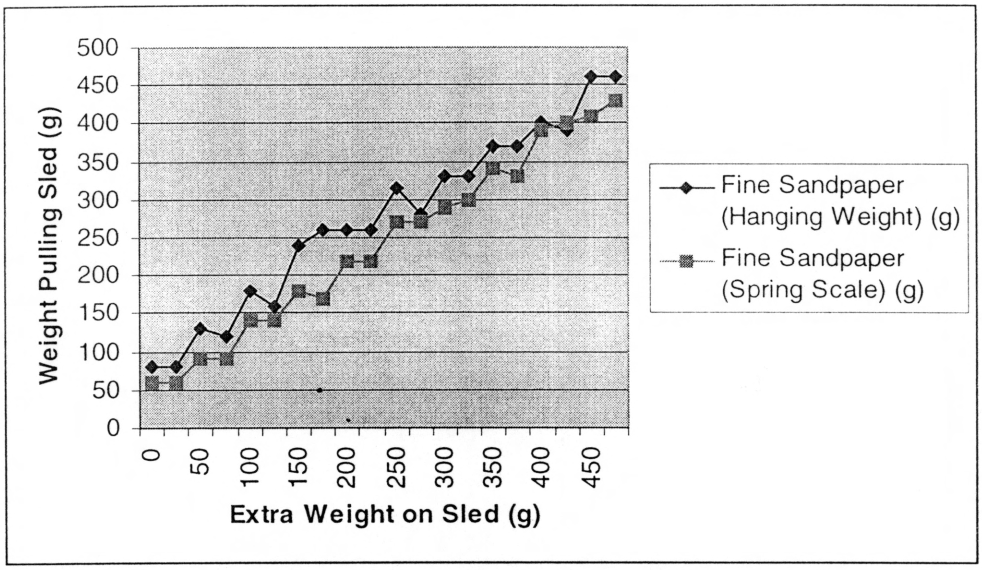

Figure 2 - Comparison of Data Obtained with Hanging Weights and Data Obtained With a Spring Scale

sandpaper using the hanging weights to measure one run from 0 to 500 grams on top of the sled, and another run measured with the spring scale. The spring scale results are slightly lower, but the testing showed that the results were repeatable. It was believed that the results were obvious enough for the fifth grade students to realize the trends and predict possible outcomes with different weights on the sled, and the sled on different materials.

The prototype was completed and the measurement method was set, so the lesson protocol needed to reflect all of the research and testing done up to that point. The driving force behind the development of the lesson protocol stems from an article from the Journal of Research in Science Teaching entitled "Teaching Science in Fifth Grade: Instructional Goals That Support Conceptual Change." The article focuses on a fifth grade science teacher named Sister Gertrude who is quoted saying, "Briefly, from a constructivist perspective, I perceive learners as actively constructing their own knowledge by using their existing knowledge to interpret new information in ways that make sense to them. As a result, learners build their own conceptual structures which subsequently foster the development of some conceptions and inhibit the development of others."[15] The protocol was designed with the intent to let the students actively construct a notion of friction that was in fact correct, yet also easily accessible with their current knowledge.

Lesson Protocols for Three Classroom Sessions at Rice School

The following is the lesson protocol that was developed prior to the three visits at the Rice School.

Objectives

1. Determine acceptability of protocol and kit by running sample experiment on test group.
2. Determine preexisting knowledge of test group by questioning before experiments. What is common sense, and what is pre-existing knowledge.
3. Find "thin areas" in lesson or apparatus and or areas which need to be improved upon

I. Group Selection
   A. Group of four to be selected
   B. Preferably a heterogeneous ability group, ranging from very able to able
   C. No discipline problems
   D. Ultimately at discretion of Mr. Skillings
   E. Learning goals for visit
      1. Can you state your own ideas?
      2. Can you talk about why you are attracted to your ideas?
      3. Are your ideas consistent?
      4. Do you realize the limitations of your ideas and the possibility they might need to change?
      5. Can you try to explain your ideas using physical models?

II. Introduction – Visit #1
   A. Display spring scale
      1. Introduce spring scale
      2. Name
      3. Function
   B. Demonstrate use of spring scale
      1. Hang one hundred gram weight
      2. Show students precise one hundred gram reading
      3. Pull object (sled) with spring scale
      4. Identify spring scale reading for students
      5. Ask students to identify spring scale reading with sled pull
      6. If results are accurate, proceed – if not, repeat step 3 till results are accurate
   C. Introduce sled and pulley system on prototype
      1. Show different materials
         a. Teflon
         b. Coarse sandpaper
         c. Fine sandpaper
      2. Pass around samples of different materials
      3. Show a run with Teflon

4. Emphasis on
   a. Setup of sled – place on surface and slide .5" to starting line
   b. Steady force applied to spring scale
   c. Reading break point value – explain and demonstrate break point
5. Ask which material will provide more resistance
6. Ask why
7. Show run with coarse sandpaper and fine sandpaper
8. Explain placing weight on sled in increments of 100 grams up to 500 grams
9. Ask what placing weight on the sled will do the spring scale reading and why

III. Experimental Session – Visit #2
   A. Assign students different tasks – rotate tasks
      1. Pull spring scale
      2. Read spring scale
      3. Set sled
      4. Place weight on sled
   B. Run 100 gram Teflon sliding measurement – close watch on students
   C. Add weight to Teflon sled
   D. Have students record measurements in sample table below

		100 grams	200 grams	300 grams	400 grams	500 grams
Teflon	run #1					
	run #2					
	average					
Coarse	run #1					
Sand	run #2					
	average					
Fine	run #1					
Sand	run #2					
	average					

   E. Walk students through any slow parts in experiment
   F. Make note of any details that need to be explained

IV. Conclusions – Analysis
   A. Ask students if they can explain the difference in numbers
      1. Observe terms students use to describe differences
      2. Determine the existing knowledge or understanding of the system
      3. Can they identify trends with increasing weights
      4. Can they identify trends with changing materials
   B. Compile notes and observations into full lesson protocol

NOTE: Friction or any other new concepts will not be mentioned or introduced by me during this short visit. The purpose or objective of this visit is to determine whether the

NOTE: Friction or any other new concepts will not be mentioned or introduced by me during this short visit. The purpose or objective of this visit is to determine whether the students are capable of producing accurate or sensible results using the current prototype. The "kid pulling" will not be attempted during visits 1 or 2.

V. Kid pulling – Visit #3
   A. Same group
   B. Materials
      1. Bath mat – one side rubber, one side furry
      2. Rope – approximately 10'
   C. Show bath mat – right side up and upside down
   D. Ask group which side of mat will provide more resistance and why
   E. Have one student sit and one student pull – let all students try each situation

VI. Conclusions – Analysis
   A. Ask students if they can explain the difference in numbers
      5. Observe terms students use to describe differences
      6. Determine the existing knowledge or understanding of the system
      7. Can they identify trends with increasing weights
      8. Can they identify trends with changing materials
   B. Compile notes and observations into full lesson protocol

Visit Procedure

The three visits to the Rice School to test and observe the lesson protocol and prototype developed to date occurred on March 24, 25, and 28 (Th, F, M), 1999. The objectives of the visit were to:

- Determine the acceptability of the protocol and the kit by running a sample experiment on a sample test group;
- Determine the preexisting knowledge of the sample test group by quizzing the students before any experimenting or demonstrating;
- Determine the distinction between common sense and actual knowledge of friction and force, and to determine the "thin areas" or areas, which were lacking in the protocol or the apparatus which needed to be improved upon.

These objectives were designed with the intent of identifying the necessary design changes and indicating needed improvements in the lesson protocol.

The group selection was essential to capturing an accurate response to the protocol and the apparatus. The important aspect was to test a group of students with heterogeneous abilities. This could represent a real fifth grade classroom situation better, because ability group is not largely in effect at a fifth grade level. The one aspect to consider which would affect the results of the study is the student teacher ratio. With the study conducted on three visits, the ratio was 4:1. This reduces discipline problems, attention problems, and explanation time. Explanation time decreases with less students because there will be less different questions.

The group that Mr. Skillings selected for testing was composed of four students named Travis, Margaret, Adam, and Monica. Travis had the strongest mathematical skills, the shortest attention span, and he caused slight disruptions in the discussions when afforded the opportunity. He appeared to get bored after the actual experimentation and used the experimental equipment as toys to play with during discussion. Margaret seemed to understand the concepts presented during the experiments and was able to predict certain trends or events, but she lacked the necessary vocabulary, such as "force" and "friction," to explain the phenomenon she was seeing in scientific terms. Adam first mentioned the word "friction" and he took charge of making the measurements. He tended to manipulate the scale to get the results he thought he should get or to stretch his reading of the scale value to the number he thought it should be. Monica had strong math skills, but she was too quiet to play an active role in the experiment. Her statements of measured results fell on deaf ears when they differed from Margaret or Adam's numbers.

The difference in ability in the group created interesting problems and questions throughout the experiments. The students were sometimes inclined to go with the first answer given to avoid a discussion of what the best number was. The discipline problems (interruptions caused by Travis playing with the apparatus, for example), as minor as they were, distracted the entire group and made it difficult to have a meaningful discussion.

The objective of the first visit was to familiarize students with a spring scale and teach the students how to operate and read the spring scale for experimental purposes. This visit occurred on Thursday, March 24. The students recognized the spring scale upon seeing it, but could not remember the name. The method for reading the scale was introduced, and the students picked that up quickly. Apparently, they had a lesson involving a spring scale in the fourth grade. The scale with the same markings found on the scale was illustrated on the chalkboard, and the students were able to read sample measurements off that as well. After measuring the weights of the sleds and other objects, the students were confident in their ability to take static measurements and repeat them accurately.

The primary objective of the second visit was to evaluate the students' use of the sled and sliding surface kit by observing a sample experimental session, and to determine whether the kit was suitable or not. The secondary objectives were to determine the strong and weak points in the kit and the curriculum and to determine any items that needed to be changed.

The setup and introduction of the second session involved displaying the prototype and the three different sleds with the different frictional surfaces fastened to the bottom surfaces (teflon, coarse sandpaper, and nothing). The procedure for taking the measurements was then demonstrated with the following points emphasized. After placing the sled on the surface, the students were instructed to move the sled by sliding it to the appropriate starting position. The next step was to add the weight called for at that step in the experiment and to pull gently on the spring scale until movement occurred. The spring scale measurement was to be taken precisely at the point at which the sled broke free from static friction.

The different sleds were passed around to the students, so that they could evaluate the differences in the surfaces, and the students were asked which material was most likely to produce the highest reading on the spring scale and why. This triggered some interesting answers that will be described later. The 100-gram weights were introduced to the students and the weights of the sleds were stated to be 100 grams as well. The testing was done with fifty gram increments, but that would have been too many trials for the students.

The intended experiment was to run pull-tests on the teflon, sandpaper, and wood sleds with 100 gram increments ranging from 0 to 500 grams. The initial teflon run produced inconsistent results, so the teflon was tested again. The second run produced equally inconsistent trends while the expected trend was a steady increasing curve. These results can be seen in Appendix B. The next material to be tested was the coarse sandpaper. This material produced an expected trend, so the students were better able to speculate and make judgements using these data. These results can also be seen in Appendix B. Next, two measurements were taken with the natural wood surface sled; one measurement was unexpected, and the other fell between the teflon and the sandpaper as expected. These results can be seen in Appendix B. After gathering the results and analyzing them a bit, the students were questioned to assess their understanding of friction in this setting.

The third visit was intended to be fun for the students, while letting them demonstrate their understanding of friction and the differences caused by different surfaces and different weights on those surfaces. Materials used in doing this were two different size shower mats with thick carpet on one side, and a non-slip rubber surface on the other. The surfaces on the mats were identical; the size was different to allow for one student on one mat, and two on the other. The intent was to have the students participate in a tug of war while considering the varying weight of the students in the experiment and predicting the who would slide using the knowledge they may or may not have gained through the earlier lessons.

Upon arrival the students were shown the shower mats and they observed the rubber side and the carpeted side. The intended experiment was explained to the students, and they were asked to predict the expected results for a straight competition with one mat rubber-side-down and the other carpet-side-down. Next, Margaret, weighing approximately 50 pounds sat on the rubber-side-down mat, and Travis, weighing approximately 80 pounds, sat on the carpet-side-down mat. The rope was given to the two of them and Travis slid along the floor immediately after the pulling began.

In the next experiment Monica sat on the rubber-side-down mat and Adam and Margaret sat on the carpet-side-down mat. This experiment consisted of approximately 65 pounds (Monica) against approximately 130 pounds (Adam + Margaret). Adam and Margaret moved first during this experiment as well. Next, I sat on the carpet-side-down mat (170 pounds) and Margaret tried to pull me from the rubber-side-down mat. I moved first, but Margaret was almost unable hold the rope. Different variations of weight on the different mats were used, but for rubber versus carpet, the rubber-side-down did not give once.

CHAPTER 4 – RESULTS

The first lesson was intentionally shortened from that described in the Lesson Plan because Mr. Skillings thought that the introduction of the spring scale itself might take up the whole lesson. He was not aware that the students had prior knowledge of a spring scale and had anticipated that a much more involved learning session would be required. The lesson could take quite a bit longer in front of an entire class, but it took no more than ten minutes with the single group of four.

The students were well equipped to handle the first visit, and they should be well equipped to handle the sections in the protocol that were skipped on that visit. The sections in the protocol that were skipped involved the use of the sled system found in the prototype, the introduction of different frictional materials, and the introduction of dynamic measurements (measuring the reading at the initiation of movement). Going over these sections the day before the readings were used in the actual experiment would be advantageous in allowing the students more practice in reading precise values with the spring scales. The spring scale was a simple tool that was very easy for the students to use, and it should not be considered an obstacle in the final lesson protocol.

The most obvious problem was that the students had trouble getting uniformly consistent results. The results were somewhat inconsistent because of the students' varying techniques in moving the spring scale until the sled began to move and because of the difficulty in reading the peak value just before the sled broke free. The results showed generally increasing friction with increasing sled weight when considered over the entire range, but some of the individual measurements showed obvious discrepancies. To compensate for these erratic results, Adam sometimes massaged the reading to be what he thought it should have been. This clouded the purpose of the experiment, and stuck out as an area needing improvement. Even when challenged gently by other students upon adjusting measurements, Adam stuck to his first reading and the students still recorded his somewhat erroneous data.

Monica had trouble getting involved with the experiment, which indicated a potential problem of not having enough different roles in the experiment and seemed to be another area needing improvement. Also, the inconsistency of the teflon tests seemed to throw off the students in their assessment of possible trends and made it more difficult for them to draw accurate conclusions. On the other hand, the coarse sandpaper showed a clear and decisive trend, which the students picked up on rather easily. This was undoubtedly because the increased friction with increased weight was so large that it was impossible to mistake. The spring scale worked well in the sandpaper case, but suffered from problems of technique when the friction measurements were small.

For the short while Mr. Skillings was present for the experimenting, it became obvious that he needed no scripted questions in order to lead the students during the second session in a discussion of force, friction, and the dependence of friction on weight. His questions led the students to use their existing knowledge to make a hypothesis, and they tested that hypothesis on the science kit. He then asked them if their hypothesis was right, and why. This constructivist style seemed to hold the students attention and forced them to think about what was happening in the situation in front of them.

The conclusions on the measurement process were as follows. The sandpaper surface worked very well, the students stayed focused, and the spring scale was a device that the students were comfortable with. The foremost negative was the technique problem demonstrated by repeated measurements. This can is addressed by the design change that calls for a longer sliding surface to allow room for the spring scale on the surface. That leaves the students room to only pull the string over the pulley and greatly reduces possible sources of error. Time did not allow the design changes to be tested, but the on site visits demonstrated clearly that the changes would prove sufficient in the attempt at increasing repeatability.

Necessary improvements on the prototype after session two were apparent. Eliminating the space between the top sliding surface and the side supports was an aspect all students agreed upon because objects were dropped into the gap. A spring scale with a maximum reading indicator would certainly benefit any student using the kit by making the reading easier to ascertain, whether fifth grade or older. The major design change, which came from the second visit, was increasing the overall length of the top surface, so the spring scale could be placed on top in front of the slider. This would force the students to pull the spring scale at the same angle every time for greater repeatability. The design changes have all been implemented, but a second round of testing at the Rice School was not done due to time constraints.

CHAPTER 5 – CONCLUSION

This project involved the design and testing of an experimental kit and curriculum to be used in a fifth grade class at the Rice School in Holden, MA on the topic of friction, force, and the use of a spring scale. The motivation for this project came from the new Massachusetts state science curriculum developed in 1998 and from Mr. Charles Skillings, a fifth-grade teacher at the Rice School, who sought assistance in addressing some of the science standards selected by him on the general topics of force and friction. The new Massachusetts standards specify desired outcomes, along with general suggestions for attaining these outcomes, but they leave the experimental details and specific lesson plans up to the individual teachers.

The curriculum influences teachers towards constructivism by suggesting physical experiments and desired outcomes that are more easily produced with physical models and hands-on activities. The force and friction outlines in the curriculum do suggest using sliding objects and a spring, which helped in the initial design phase by providing a starting point. Other ideas suggested are the use of sandpaper and lubricants to demonstrate influential characteristics of friction.

Observing Mr. Skillings working with the students and science kit for the ten minutes he was able to join the session indicated that his constructivist teaching style coupled with the science kit will be a successful endeavor in teaching his students about friction. The third day with the shower mats demonstrated that the students had learned something about friction and its relation to different materials. Working with the state guidelines was actually beneficial to the project because they did not hamper the project's progress, while at the same time they provided enough direction to keep the project in line with the intended results.

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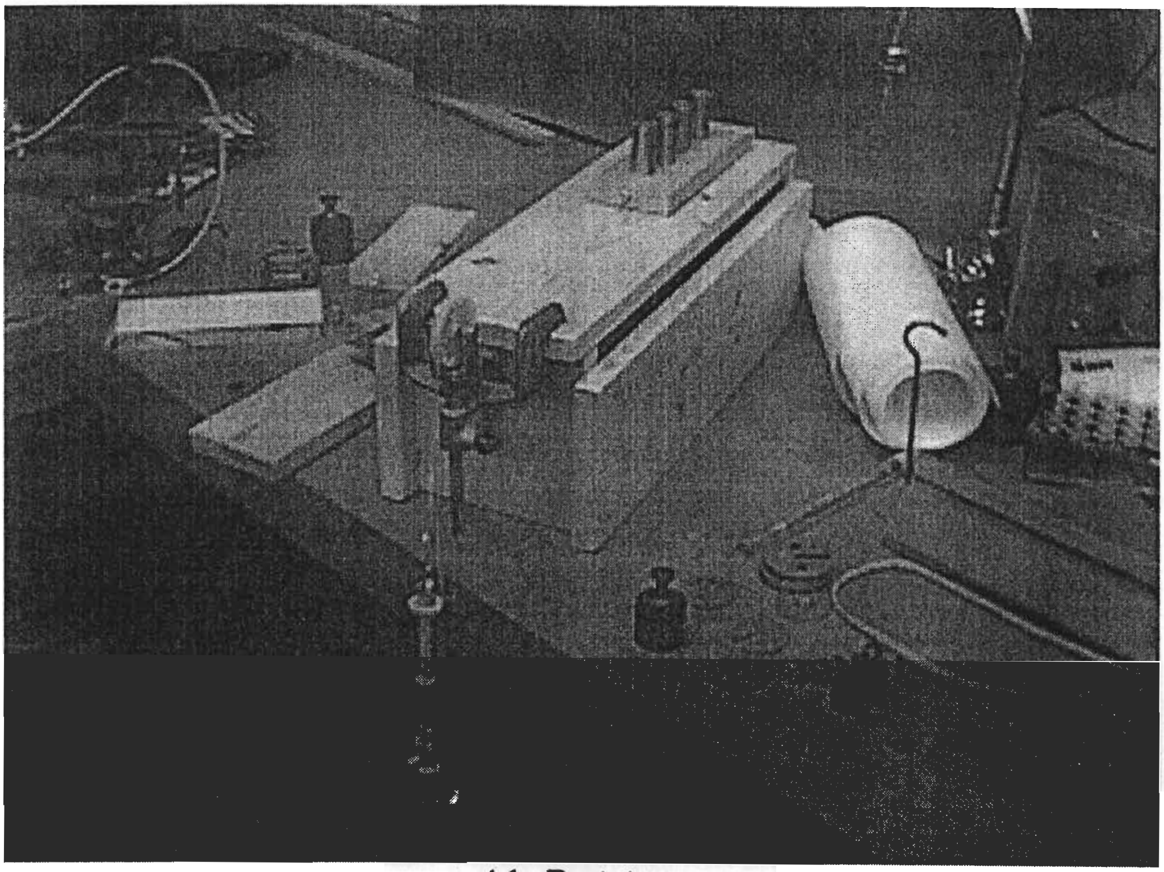
Appendix A
Massachusetts Fifth Grade Science Curriculum
and Photo of Apparatus



A1 - Prototype

Science Curriculum

Grade 5

Early Science - Curric

Science Curriculum
Grade: 5

Physical Science

Outcome (The student will...)	Instructional Strategies (The teacher may...)	Learning Activity (The student may...)
1 Define Friction. riding bikes in different kinds of weather	Will have students rub hands together to define concepts of push-pull - force-friction as the force opposing movement. put lubricant between	Use a friction board and note the various amounts of forces that are needed to move objects.
2 Describe the relationship between friction and force.	Have students use sandpaper and lubricants to explore differences. try different surfaces →	Select 4 objects of equal weight Using spring scale measure force needed to move objects. Graph comparative data. Label and share.
3 Using a spring scale, measure friction between chosen sliders and surfaces. skiing roller blades ice skates	Collect sample objects of varying weights. Model activity to demonstrated experiment. Develop a hypothesis and conduct experiments using the weights and string to move objects.	Student moves the varying objects with string attached to spring scale. Data is recorded, analyzed.
1 Measure volume by calculation, experimentation. different sized containers	Define volume as the amount of space that it occupies. Demonstrate the math: Volume = 1 x w x h	Use 6 different containers - measure volume by displacing liquid or sand with solid object. To calculate the volume of an object using math.

Science Curriculum
Grade: 5

Physical Science

Assessment	Extension (The student will...)	Resources
Prepare a lab report describing experiment and results.	Take different types of material and rug on rug. Which is hardest to move? Easiest? Start with this Something you feel - Skidding - Bowling Ball "Football Game" using different kinds of paper.	- *Science Through Experiments* Program, Ch 1-1. - Spring scale 250 mg. - *Science Alive: all About Forces* Inertia - what it takes to get something in motion.
Lab report recording force of each pull.	Using sandpaper: place object on sandpaper and move objects using lubricant are not same.	- Spring scale. - Sandpaper. - Lubricant (hand cream). - 4 equal weight objects. - *Science Through Experiments 1-1.* - *Science Alive: all About Forces.*
Create circle, bar, and line graphs to depict results.	Using a variety of additional weights and surface texture conduct additional experimentation. Use same specimens on surfaces that are treated with sand, lubricants and other materials. Record results, graph data.	- Spring scales. - Charts. - Surfaces of various textures. - Weights. - *Science Alive: all About Forces*

Science Curriculum

Physical Science **Grade: 5**

Outcome (The student will...)	Instructional Strategies (The teacher may...)	Learning Activity (The student may...)
5 Measure volume by calculation, experimentation.	Define volume as the amount of space that it occupies. Demonstrate the math: Volume = l x w x h	- Use 6 different containers - measure volume by displacing liquid or sand with solid object. - Calculate the volume of an object using math.
6 Identify parts of a Class I Lever: effort area - what picks up fulcrum load arm - what gets picked up	- Draw example of Class I lever on overhead. - Tape 3 pencils together in a triangular formation as fulcrum. Use ruler to model a lever. Place varying size blocks on either side of the fulcrum and balance.	Chart the effort and load capacities of the lever and move fulcrum point to adjust variables. Record results. Compare.
7 Predict amount of effort needed to move load.	Demonstrate use of a spring scale.	- Select a variety of classroom objects. Predict which will require light effort and those that will require more force to move. - Place objects on similar surfaces; measure force required to move them. Record data. Compare to predictions.
8 Build a simple circuit using: - a. battery, bulbs, wires - b. battery, bulbs, wires, switches - c. battery, bulbs, wires, buzzers - d. battery, bulbs, wires, motors	Explain procedure and model the assembly of circuits.	Create closed and open circuits - draw schematic diagrams and demonstrate same.

Science Curriculum
Grade: 5

Physical Science

	essment	Extension (The student will...)	Resources
5	- Make a bar graph of each object's displacement. - Diagram procedures - Quantitative results.	- Use a variety of common containers to determine volume by dis-place-ment. - Locate various common containers and determine volume mathemati-cally and by displacement.	- *Science Through Experiments*, Program 3-1. - *Science Through Experiments*, Program chapter 3 - *TOPS Metric Measuring* - *TOPS: More Metric*
5	Observe and record measurement of the experiment - chart and graph variables.	- Use weights and attach to effort end of lever and use other weights for the load part — move fulcrum point and observe changes. - *Balance Bazaar* : *AIMS* Vol. XI No. Dec. 1996	- *Science Through Experiments*, Program, pp. 2-1. - *TOPS : Balancing* - *Take Home Science* by Feely Heinemann. - *Science Alive: All About Forces.* - *Stepping Stone to Science* by Kendall Haven.
	Describe experiment in a lab report.	Create a story wheel of 8 common objects and the force required to move them.	- *Science Through Experiment.* - *Science Alive: All About Forces.*
8	Teacher observations. Schematic diagrams.	Conduct additional experiments using "double" of materials, i.e., 2 bulbs 2 x length wires 2 batteries 3 batteries	- Electrical components. - *STEP* - Chapter 4. - Boston Museum of Science - Kit Rental. - *Science Alive: Exploring Energy.* - *TOPS: Electricity.*

Science Curriculum

Physical Science

Grade: 5

	Outcome (The student will...)	Instructional Strategies (The teacher may...)	Learning Activity (The student may...)
9	Use voltage meter to measure different amounts of energy required for each of the above.	Explain procedures for proper use of VOM test instrument.	Using meter, connect batteries in series on parallel to measure voltage.
10	Experiment, collect data, graph results and draw conclusions (Scientific Process).	Explain the process of collecting data - analyzing and drawing conclusion.	Collect all milk cartons from cafeteria - various types counted and data graphed.
11	Define the atom and its basic parts.	Show a model or picture of atom. Review the action of molecules in solid, liquid and gas.	Work with a partner to draw a diagram or create a model of an atom. Label parts.

Physical Science

	Assessment	Extension (The student will...)	Resources
9	Teacher observation of experiments and recording of measurements.	Conduct resistance experiments of copper, aluminum, steel and various resistors.	- Volt ohm meter. - *Science Alive: Exploring Energy.* - *TOPS: Electricity.* - *STEP* - Chapter 4.
10	Teacher evaluation of graphs.	Students will create physical shapes of collected data.	Cafeteria.
11		Create a mnemonic device to help remember the parts of an atom. Research the relative size of an atom. Relate to common objects.	- Models/diagrams of solids, liquids and gases. - Science text. - Reference material, esp. Internet.

Appendix B
Test results

Prototype Testing: Force Required to Overcome Static Friction

Weight on Sled (g)	Wood (Hanging Weight) (g)	Metal (Hanging Weight	Teflon (Hanging Weight) (g)	Fine Sandpaper (Hanging Weight) (g)
50	25	40	25	80
50	30	45	25	80
100	55	70	40	130
100	57	70	35	120
150	80	90	50	180
150	80	90	50	160
200	100	110	65	240
200	100	110	70	260
250	120	130	70	260
250	120	140	70	260
300	150	170	80	315
300	150	170	80	280
350	170	190	100	330
350	170	190	100	330
400	210	220	100	370
400	180	220	110	370
450	210	250	110	400
450	200	250	110	390
500	220	270	120	460
500	250	270	130	460

Medium Sandpaper (Hanging Weight) (g)	Coarse Sandpaper (Hanging Weight) (g)	Fine Sandpaper (Spring Scale) (g)	Medium Sandpaper (Spring Scale) (g)	Coarse Sandpaper (Spring Scale) (g)
90	80	60	60	70
80	90	60	60	60
120	120	90	90	110
120	130	90	90	130
150	150	140	120	170
150	150	140	130	170
200	240	180	150	250
220	200	170	160	160
230	230	220	190	210
230	220	220	200	220
270	310	270	220	270

250	270	270	230	280
280	350	290	260	290
290	340	300	260	290
330	350	340	310	310
340	380	330	320	330
370	390	390	330	370
380	390	400	340	350
410	400	410	370	380
440	390	430	380	410

rev: 2/12/99

Prototype Testing: Force Required to Overcome Static Friction
Testing Performed by students

Weight on Sled (g)	Teflon (Spring Scale)	Coarse Sandpaper (Spring Scale) (g)	Wood (Spring Scale) (g)
100	30	65	
100	40	70	
100	25		
100	30		
200	70	150	
200	90	180	
200	80		
200	70		
300	130	260	90
300	110	250	70
300	50		
300	60		
400	120	330	
400	110	350	
400	90		
400	90		
500	160	395	160
500	120	405	150
500	105		
500	95		

rev. 5/3/99